

# INTERNATIONAL PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

## NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner  
US Department of Commerce  
United States Patent and Trademark  
Office, PCT  
2011 South Clark Place Room  
CP2/5C24  
Arlington, VA 22202  
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year)

19 July 2001 (19.07.01)

International application No.

PCT/US00/25962

Applicant's or agent's file reference

FP68450/JAS

International filing date (day/month/year)

21 September 2000 (21.09.00)

Priority date (day/month/year)

21 September 1999 (21.09.99)

Applicant

HAN, Cheol-Hyun et al

1. The designated Office is hereby notified of its election made:



in the demand filed with the International Preliminary Examining Authority on:

19 April 2001 (19.04.01)



in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was



was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO  
34, chemin des Colombettes  
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Zakaria EL KHODARY

Telephone No.: (41-22) 338.83.38

**THIS PAGE BLANK (USPTO)**

# PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:  
JAMES A. SHERIDAN  
FLEHR HOHBACH TEST ALBRITTON &  
HERBERT LLP  
4 EMBARCADERO CENTER, SUITE 3400  
SAN FRANCISCO, CA 94111-4187

## PCT

NOTIFICATION OF TRANSMITTAL OF  
THE INTERNATIONAL SEARCH REPORT  
OR THE DECLARATION

(PCT Rule 44.1)

Applicant's or agent's file reference FP68450/JAS (S-8)	Date of Mailing (day/month/year) <b>29 DEC 2000</b>
International application No. PCT/US00/25962 ✓	International filing date (day/month/year) <b>21 September 2000 (21.09.2000)</b> ✓
Applicant UNIVERSITY OF HAWAII	

1. ☒ The applicant is hereby notified that the international search report has been established and is transmitted herewith.  
**Filing of amendments and statement under Article 19:**  
 The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

**When?** The time limit for filing such amendments is normally 2 months from the date of transmittal of the international search report; however, for more details, see the notes on the accompany sheet.

**Where?** Directly to the International Bureau of WIPO  
 34, chemin des Colombettes  
 1211 Geneva 20, Switzerland  
 Facsimile No.: (41-22) 740.14.35

**Comments on Abstract due** 11/29/01  
**Rspn to Int'l Search due** 2/28/01  
**Review Foreign Refs (U.S.)**                     

For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. ☐ With regard to the protest against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.  
☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after 18 months from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in rules 90 bis 1 and 90 bis 3, respectively, before the completion of the technical preparations for international publication.

Within 19 months from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within 20 months from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Anita Alanko Jean Proctor Paralegal Specialist
Telephone No. 703-308-0661	

**THIS PAGE BLANK (USPTO)**

# PATENT COOPERATION TREATY

## PCT

### INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference FP68450/JAS	<b>FOR FURTHER ACTION</b>	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/US00/25962	International filing date ( <i>day/month/year</i> ) 21 September 2000 (21.09.2000)	(Earliest) Priority Date ( <i>day/month/year</i> ) 21 September 1999 (21.09.1999)
Applicant UNIVERSITY OF HAWAII		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.



It is also accompanied by a copy of each prior art document cited in this report.

**1. Basis of the Report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.



the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:



contained in the international application in written form.



filed together with the international application in computer readable form.



furnished subsequently to this Authority in written form.



furnished subsequently to this Authority in computer readable form.



the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.



the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of invention is lacking** (See Box II).

4. With regard to the **title**,



the text is approved as submitted by the applicant.



the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,



the text is approved as submitted by the applicant.



the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1A



as suggested by the applicant.



because the applicant failed to suggest a figure.



because this figure better characterizes the invention.



None of the figures

**THIS PAGE BLANK (USPTO)**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/25962

### Box III TEXT OF THE ABSTRACT (Continuation of Item 5 of the first sheet)

#### NEW ABSTRACT

A micromachined acoustic transducer 100 comprising a parylene diaphtagm 124 piezoelectric transducer. The parylene diaphragm has far lower stiffness than silicon nitride. The method for fabricating the parylene diaphragm acoustic transducer utilizes a prestructured diaphragm layer utilizing silicon nitride which is compatible with high temperature semiconductor processing. A silicon nitride layer is patterned and partially removed after forming the parylene diaphragm layer in order to enhance the structural qualities of the parylene diaphragm. The diaphragm may be flat or dome-shaped.

**THIS PAGE BLANK (USPTO)**



# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/25962

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H04R 25/00, 31/00

US CL : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
WEST (USPATFULL, JPO abstracts, EPO abstracts, WPIDS, IBM TDB)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,783,821 A (MULLER et al) 08 November 1988 (08.11.1988), column 2, lines 6-34.	1-21
Y	US 5,209,118 A (JERMAN) 11 May 1993 (11.05.1993), column 6, line 65-column 7, line 8.	1-21
Y	US 5,490,220 A (LOEPPERT) 06 February 1996 (06.02.1996), column 4, lines 47-64).	6-11, 14-21
A	US 4,607,145 A (RAVINET et al) 19 August 1986 (19.08.1986), column 2, lines 50-53.	
A	US 5,870,351 A (LADABAUM et al) 09 February 1999 (09.02.1999), column 4, lines 51-59.	
A	US 5,479,061 A (BOBBIO et al) 26 December 1995 (26.12.1995).	
A	WO 99/24744 A1 (CALIFORNIA INSTITUTE OF TECHNOLOGY) 20 May 1999 (20.05.1999).	

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

07 December 2000 (07.12.2000)

Date of mailing of the international search report

29 DEC 2000

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703)305-3230

Authorized officer

Anita Alanko

Telephone No. 703-308-0661

Jean Proctor  
Paralegal Specialist

**THIS PAGE BLANK (USPTO)**

# PATENT COOPERATION TREATY

## PCT

### INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

REC'D 26 MAR 2002

WIPO PCT

Applicant's or agent's file reference <b>FP68450/JAS</b>	<b>FOR FURTHER ACTION</b>		See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. <b>PCT/US00/25962</b>	International filing date (day/month/year) <b>21 September 2000 (21.09.2000)</b>	Priority date (day/month/year) <b>21 September 1999 (21.09.1999)</b>	
International Patent Classification (IPC) or national classification and IPC <b>IPC(7): H04R 25/00, 31/00 and US Cl.: 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426</b>			
Applicant <b>UNIVERSITY OF HAWAII</b>			
<p>1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.</p> <p>2. This REPORT consists of a total of <u>3</u> sheets, including this cover sheet.</p> <p><input type="checkbox"/> This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).</p> <p>These annexes consist of a total of <u>0</u> sheets.</p>			
<p>3. This report contains indications relating to the following items:</p> <ul style="list-style-type: none"> <li>I <input checked="" type="checkbox"/> Basis of the report</li> <li>II <input type="checkbox"/> Priority</li> <li>III <input type="checkbox"/> Non-establishment of report with regard to novelty, inventive step and industrial applicability</li> <li>IV <input type="checkbox"/> Lack of unity of invention</li> <li>V <input checked="" type="checkbox"/> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement</li> <li>VI <input type="checkbox"/> Certain documents cited</li> <li>VII <input type="checkbox"/> Certain defects in the international application</li> <li>VIII <input type="checkbox"/> Certain observations on the international application</li> </ul>			
Date of submission of the demand <b>19 April 2001 (19.04.2001)</b>		Date of completion of this report <b>11 March 2002 (11.03.2002)</b>	
Name and mailing address of the IPEA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230		Authorized officer  <b>Anita Alanko</b>  Telephone No. 703-308-0661  <div style="text-align: right;">Jean Proctor Paralegal Specialist</div>	

**THIS PAGE BLANK (USPTO)**

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/US00/25962

**I. Basis of the report****1. With regard to the elements of the international application:\***

- ☒ the international application as originally filed.
- ☒ the description:  
pages 1-11 as originally filed  
pages NONE, filed with the demand  
pages NONE, filed with the letter of \_\_\_\_\_.
- ☒ the claims:  
pages 12-15, as originally filed  
pages NONE, as amended (together with any statement) under Article 19  
pages NONE, filed with the demand  
pages NONE, filed with the letter of \_\_\_\_\_.
- ☒ the drawings:  
pages 1-10, as originally filed  
pages NONE, filed with the demand  
pages NONE, filed with the letter of \_\_\_\_\_.
- ☐ the sequence listing part of the description:  
pages NONE, as originally filed  
pages NONE, filed with the demand  
pages NONE, filed with the letter of \_\_\_\_\_.

**2. With regard to the language, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.**

These elements were available or furnished to this Authority in the following language \_\_\_\_\_ which is:

- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

**3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:**

- ☐ contained in the international application in printed form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

**4. ☒ The amendments have resulted in the cancellation of:**

- ☒ the description, pages none
- ☒ the claims, Nos. none
- ☒ the drawings, sheets/fig none

**5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).\*\***

\* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

\*\* Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.

**THIS PAGE BLANK (USPTO)**

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.  
PCT/US00/25962**V. Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement****1. STATEMENT**

Novelty (N)	Claims <u>1-21</u>	YES
	Claims <u>NONE</u>	NO
Inventive Step (IS)	Claims <u>2,6-11 and 14-21</u>	YES
	Claims <u>1,3-5,12 and 13</u>	NO
Industrial Applicability (IA)	Claims <u>1-21</u>	YES
	Claims <u>NONE</u>	NO

**2. CITATIONS AND EXPLANATIONS**

Claims 1, 3-5, 12-13 lack an inventive step under PCT Article 33(3) as being obvious over Muller et al (US 4,783,821 A) in view of Jerman (US 5,209,118 A), Ladabaum et al (US 5,870,351 A) and Loeppert (US 5,490,220 A).

Muller discloses a diaphragm transducer and a method of making a diaphragm transducer comprising:

providing a silicon substrate 27 and depositing layers of a bottom conductive layer polysilicon 25, silicon oxide 23, zinc oxide 21, silicon oxide 29 and a top conductive layer of aluminum 24;  
depositing a layer of silicon nitride as a diaphragm 22;  
patterning contact holes to the bottom and top conductive layers (col.8, line 38, "step 15");  
releasing the diaphragm by removing portions of the silicon substrate by backside etching (col.6, lines56+ , "step 5").

Muller does not disclose to deposit backside silicon nitride on the substrate. Rather, Muller discloses to use a photoresist as an etch mask. However, it is conventional in the art to use silicon nitride as an etch mask for etching silicon. Therefore, it would have been obvious to one with ordinary skill in the art to use silicon nitride for the backside etch mask because its use is conventional in the art for etching silicon.

Muller does not disclose to use an insulating layer of parylene. Ladabaum et al teaches that silicon oxide and parylene are alternative insulating materials (see claims 3 and 4). It would have been obvious to one with ordinary skill in the art to use parylene in place of silicon oxide in the method of Muller because Ladabaum teaches that they are known alternative insulating materials.

Muller does not disclose to use parylene as the diaphragm material. Rather, Muller discloses to use silicon nitride as the diaphragm. Jerman teaches that in transducer applications, that it is known that diaphragms can be formed of silicon nitride or parylene (col.7, lines 1-5). The choice depends on the application and device characteristics sought. Therefore, it would have been obvious to one with ordinary skill in the art to use parylene as the diaphragm in the method of Muller because Jerman teaches that they are known alternative diaphragm materials.

Muller discloses to use polysilicon as the bottom conductive layer, not aluminum. Loeppert teaches that polysilicon and aluminum are known alternative conductive materials (col.3, lines 41-45). It would have been obvious to use aluminum as the bottom conductive layer in the method of Muller because Loeppert teaches that aluminum and polysilicon are known alternative conductive materials.

Claims 2, 6-11, 14-21 meet the criteria set out in PCT Article 33(2)-(4), because the prior art does not teach or fairly suggest patterning a topside or backside layer of silicon nitride to provide support for the parylene diaphragm.

----- NEW CITATIONS -----□□

**THIS PAGE BLANK (USPTO)**



(19) World Intellectual Property Organization  
International Bureau



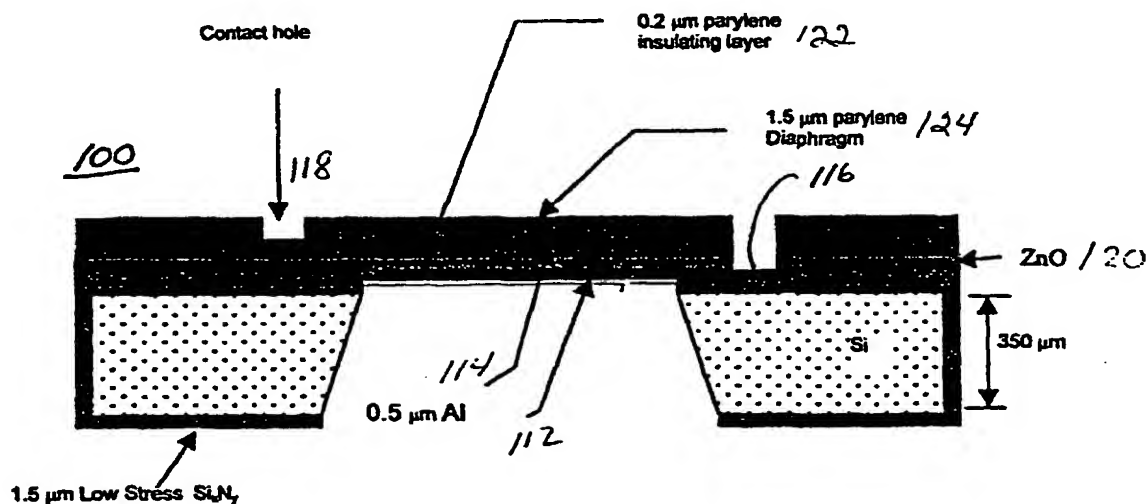
(43) International Publication Date  
29 March 2001 (29.03.2001)

PCT

(10) International Publication Number  
**WO 01/22776 A1**

- (51) International Patent Classification<sup>7</sup>: **H04R 25/00**, 31/00
- (21) International Application Number: **PCT/US00/25962**
- (22) International Filing Date:  
21 September 2000 (21.09.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
60/155,045 21 September 1999 (21.09.1999) US
- (71) Applicant (for all designated States except US): **UNIVERSITY OF HAWAII [US/US]**; 2800 Woodlawn Drive, Suite 280, Honolulu, HI 96822 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **HAN, Cheol-Hyun [KR/US]**; 2724 Kaloaloha Ln. #1403, Honolulu, HI 96826 (US). **KIM, Eun, Sok [US/US]**; 4461 PCH #C104, Torrance, CA 90505 (US).
- (54) Agents: **SHERIDAN, James, A. et al.; Flehr Hobbach Test Albritton & Herbert LLP**, 4 Embarcadero Center, Suite 3400, San Francisco, CA 94111-4187 (US).
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:  
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS**



(57) Abstract: A micromachined acoustic transducer (100) comprising a parylene diaphragm (124) piezoelectric transducer. The parylene diaphragm has far lower stiffness than silicon nitride. The method for fabricating the parylene diaphragm acoustic transducer utilizes a prestructured diaphragm layer utilizing silicon nitride which is compatible with high temperature semiconductor processing. A silicon nitride layer is patterned and partially removed after forming the parylene diaphragm layer in order to enhance the structural qualities of the parylene diaphragm. The diaphragm may be flat or dome-shaped.

WO 01/22776 A1

**THIS PAGE BLANK (USPTO)**

## METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS

### Cross-Reference to a Related Application

5 The present application is based on a provisional application Serial No. 60/155,045 filed September 21, 1999, and entitled METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS; this provisional application is incorporated herein by reference, and the priority of the provisional application is claimed herein.

### Field of the Invention

10 The present invention relates to the micromachined acoustic transducers and their fabrication technology. More particularly this invention relates to parylene-diaphragm piezoelectric acoustic transducers on flat and dome-shaped diaphragm in silicon substrate.

### Background of the Invention

15 Recently, there has been increasing interest in micromachined acoustic transducers based on the following advantages: size miniaturization with extremely small weight, potentially low cost due to the batch processing, possibility of integrating transducers and circuits on a single chip, lack of transducer "ringing" due to small diaphragm mass. Especially, these advantages make the micromachined acoustic transducers, such as microphone and micro speaker, attractive in the applications for personal communication  
20 systems, multimedia systems, hearing aids and so on.

Micromachined acoustic transducers are provided with a thin diaphragm and several diaphragm materials that must be compatible with high temperature semiconductor process,

**THIS PAGE BLANK (USPTO)**

such as silicon nitride and silicon have been utilized as diaphragm. However, micromachined acoustic transducers made by these conventional diaphragm materials suffer from a relatively low sensitivity and it is mainly because of the high stiffness and residual stress of these diaphragm materials.

5 In order to implement the micromachined acoustic transducers with competitive performance with conventional acoustic transducers, it is necessary to find new diaphragm materials that have low stiffness and compatibility with semiconductor processing at the same time. Also, the transducer should be designed to release or minimize the residual stress of the diaphragm.

#### 10 Summary of the Invention

The present invention relates to piezoelectric acoustic transducers and improved methods of making such transducers.

15 In accordance with one embodiment of the invention, the piezoelectric transducer is made of parylene; in accordance with a further embodiment of the invention, the parylene diaphragm is supported by a patterned silicon nitride layer.

In accordance with a further aspect of the invention, the diaphragm is made in accordance with a process utilizing a silicon nitride diaphragm layer which is compatible with high temperature semiconductor processing.

20 In summary, the present invention comprises a micromachined acoustic transducer comprising a parylene-diaphragm piezoelectric transducer. The parylene diaphragm has far lower stiffness than silicon nitride which has been the dominant technology for micromachined diaphragms, and provides higher performing acoustic devices. The parylene diaphragm is almost free from the residual stress problem, and considerably reduces  
25 transducer sensitivity.

The invention further comprises a method for fabricating the parylene diaphragm acoustic transducer utilizing a prestructured diaphragm layer utilizing silicon nitride which is compatible with high temperature semiconductor process.

30 In a preferred embodiment, the silicon nitride layer is patterned and partially removed after forming the parylene diaphragm layer in order to enhance the structural qualities of the parylene diaphragm.

**THIS PAGE BLANK (USPTO)**

In a further refinement of the process, a shadow masking technique utilizing high deposition rate thermal evaporation for conformal deposition of a metal electrode on a dome-shaped parylene diaphragm is utilized.

In an especially preferred embodiment, the parylene diaphragm acoustic transducer is a dome-shaped diaphragm which especially provides the following advantages:

- (1) a dome diaphragm releases residual stress in the diaphragm through its volumetric shrinking or expansion;
- (2) a dome diaphragm piezoelectric transducer produces its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm);
- (3) a dome diaphragm transducer has a higher figure of merit (the product of the fundamental resonant frequency squared and the dc response) than a flat diaphragm based transducer.

Other features and advantages of the invention will become apparent to a person of skill in the art who studies the following description of the preferred and exemplary embodiments, given in association with the following figures.

#### Brief Description of the Drawings

FIG. 1A is a cross-sectional view drawing of the parylene piezoelectric flat diaphragm acoustic transducer;

FIG. 1B is a top view photo of a fabricated parylene flat diaphragm acoustic transducer;

FIG. 1C is a bottom view photo of the parylene flat diaphragm acoustic transducer;

FIG. 2A is a cross-sectional view drawing of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

FIG. 2B is a top view photo of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

FIG. 2C is a bottom view photo of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

FIGS. 3A-3H are the processing steps to fabricate the parylene flat-diaphragm acoustic transducers and the parylene-held cantilever-like-diaphragm acoustic transducers;

**THIS PAGE BLANK (USPTO)**



FIGS. 4A-4H show the processing steps to fabricate the parylene piezoelectric dome-shaped diaphragm acoustic transducer with the shadow-mask patterning method;

FIGS. 5A-5F show the processing steps to fabricate the shadow mask using anisotropic and isotropic etching technique;

FIGS. 6, 7, 8, 9A-9C and 10A-10B illustrate various cantilever type parylene diaphragm acoustic transducers which can be fabricated using the technology described above.

#### Detailed Description of the Invention

Microelectromechanical Systems (MEMS) technology has been used to fabricate tiny microphones and microspeakers on a silicon wafer. This method of fabricating acoustic transducers on a silicon wafer has the following advantages over the more traditional methods: potentially low cost due to the batch processing, possibility of integrating sensor and amplifier on a single chip, and size miniaturization. Furthermore, a thin-diaphragm-based miniature acoustic transducer has low vibration sensitivity due to the small diaphragm mass.

Compared to more popular condenser-type MEMS microphones, piezoelectric MEMS microphones are simpler to fabricate, free from any polarization-voltage requirement, and responsive over a wider dynamic range. However, a piezoelectric MEMS microphone suffers from a relatively low sensitivity, mainly due to high stiffness of the diaphragm materials used for the microphone. The thin film materials currently used for a diaphragm such as silicon nitride, silicon, and polysilicon were adopted because they are compatible with semiconductor processing techniques; but these materials have high stiffness and residual stress. High temperature semiconductor processing hinders the usage of more flexible materials such as polymer films as diaphragm materials, though many conventional bulky acoustic transducers use polymer diaphragm to improve the performance.

As a new approach for building micromachined acoustic transducers, parylene micromachined piezoelectric acoustic transducers are proposed. A parylene diaphragm that has about 100 times lower stiffness than silicon nitride, considerably increases the sensitivity at audio range compared with that of a conventional device made by silicon nitride

**THIS PAGE BLANK (USPTO)**

diaphragm. Also, the parylene diaphragm is almost free of the residual stress problem which considerably reduces the sensitivity of prior art transducers.

Although parylene could be fabricated in either a flat or dome shape, a parylene piezoelectric dome-shaped diaphragm is especially useful, as it has the following advantages:  
5 it releases residual stress in the diaphragm through its volumetric shrinkage or expansion;  
it produces its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm); and it has a higher figure of merit (the product of the fundamental resonant frequency squared and the dc response) than a flat diaphragm transducer. Therefore it generates ultrasonic sound effectively.

## 10 FABRICATION

### *A. Parylene flat diaphragm acoustic transducer*

A schematic of the process flow for the parylene micromachined piezoelectric flat diaphragm acoustic transducer (illustrated in Figs. 1A-1C) is shown in Fig. 3. First, 1  $\mu\text{m}$  thick low stress silicon nitride 300 is deposited by low pressure chemical vapor deposition  
15 (LPCVD) on a bare silicon substrate 302, followed by depositions of 0.5  $\mu\text{m}$  thick bottom Al 304, 0.5  $\mu\text{m}$  thick ZnO 306, 0.2  $\mu\text{m}$  thick parylene 308, and 0.5  $\mu\text{m}$  thick top Al 310. Then 1.5  $\mu\text{m}$  thick parylene 312 is deposited as a diaphragm. Contact holes 314 are patterned through bottom and top electrode 304, 310 which are provided by the Al. To release the diaphragm structure, backside silicon nitride 320 is patterned, and silicon  
20 substrate 302 is removed by KOH etching. Finally, the silicon nitride 330 most bottom layer of diaphragm structure is either completely removed for the parylene flat-diaphragm acoustic transducers or selectively patterned for the parylene-held cantilever-like-diaphragm acoustic transducers.

The completed transducer 100 is shown in Figs. 1A-1C. Fig. 1A shows the layers  
25 of the transducer in cross-section, including the Al contact layers 112, 114 to contact 116, 118; the ZnO layer 120 which is provided to establish the desired transducer function; the thin insulating parylene layer 122 which separates the electrodes; and the parylene diaphragm layer 124. Several of these layers also appear in Figs. 1B and 1C, top and bottom views, respectively.

**THIS PAGE BLANK (USPTO)**

The parylene-held cantilever-like-diaphragm transducer formed by selectively patterning bottom  $\text{Si}_x\text{N}_y$  appears especially in Figs. 3E-3H.

*B. Parylene dome-shaped diaphragm acoustic transducer*

A schematic of the process flow for the parylene micromachined piezoelectric dome-shaped diaphragm acoustic transducer is 200 which is shown in Figs. 2A-2C is shown in Fig. 4: First,  $1\text{ }\mu\text{m}$  thick low stress silicon nitride 402 is deposited by low pressure chemical vapor deposition (LPCVD) on a bare silicon substrate 400 to prevent any possible contamination from the polyethylene tape used in subsequent processing steps. Also, this silicon nitride layer 402 functions as an etch mask in during a secondary isotropic etch of the silicon substrate (which is a step to improve the etch-front circularity and smoothness simultaneously). A polyethylene tape 404 is then pasted on the silicon nitride 402, and patterned in a reactive ion etcher (RIE) with Oxygen plasma (in this RIE step, Al 406 is used as an etch mask). After patterning the tape (Fig. 4B), the Al film is removed by an Al etchant (1g KOH: 10g  $\text{K}_3\text{Fe}(\text{CN})_6$ : 100ml DI water) which rarely deteriorates the tape adhesion. Tape is then used to cover the bottom and side areas. Then the silicon 400 is etched (Fig 4C) in an isotropic silicon etchant to form spherical etch fronts, followed by dissolving the polyethylene tape 404 in toluene. The etching may be performed in a Teflon beaker (without any agitation for uniform etch-stop effect) which is placed in a  $50^\circ\text{C}$  water bath.

An additional isotropic etching after removing the polyethylene tape (Step 9) may be needed to improve the circularity and surface roughness of the etch front which is to serve as a mold to define the dome diaphragm. After obtaining the dome-shaped etch cavity,  $1.5\text{ }\mu\text{m}$  thick slightly-compressive silicon nitride 422 is deposited on the wafer. Then a  $0.5\text{ }\mu\text{m}$  thick bottom Al 430 is deposited with thermal evaporation by using shadow mask technique illustrated by mask 432 (Fig. 4E). This is followed by  $0.5\text{ }\mu\text{m}$  thick ZnO 434,  $0.2\text{ }\mu\text{m}$  thick parylene 436, and  $0.5\text{ }\mu\text{m}$  thick top Al 438 deposited (Fig. 4F) with thermal evaporation by using shadow mask technique again. Then  $1.5\text{ }\mu\text{m}$  thick parylene 440 is deposited as parylene diaphragm layer. Next contact holes 450, 452 (Fig. 4B) are patterned through bottom and top aluminum electrode. To release the diaphragm structure (Fig. 4H), silicon substrate 400 is removed by KOH etching after backside silicon is patterned. Finally,

**THIS PAGE BLANK (USPTO)**

the silicon nitride most bottom layer 422 of diaphragm structure is either completely removed for the parylene flat-diaphragm transducers or selectively patterned for the parylene-held cantilever-like-diaphragm transducers.

The sequence of layers is the same as explained in Fig. 1A, including patterned  
5 SiN 210; Al contact layers 112, 114 leading to contacts 116, 118; ZnO layer 120; thin parylene insulating layer 122; and parylene diaphragm layer 224.

## SHADOW MASK TECHNIQUE WITH HIGH DEPOSITION RATE THERMAL EVAPORATION

In order to get high resolution patterning in dome-shaped diaphragm and avoid  
10 disconnection problem of electrodes at a sharp edge boundary, a shadow mask technique with high deposition-rate thermal evaporation has been developed.

High resolution patterning in non-planar substrate surfaces is an often-encountered problem in a micromachined process. It is because that conventional patterning method with spin coating of photoresist can not be used. Even if conformal photoresist coating  
15 method, such as PEPR2400, is used, the patterning should be limited by the step angle of substrate surface. That is, sharp edges are still hard to pattern because the effective thickness of photoresist is too thick and the light source does not penetrate underneath photoresist.

The shadow mask of Fig. 5 is made of a <100> oriented 3-inch silicon wafer 600.  
20 Fig. 5 illustrates the fabrication steps of the shadow mask using anisotropic and isotropic etching. First, 1  $\mu\text{m}$  silicon nitride 502 is deposited (Fig. 5A) on the silicon substrate 500 and the backside silicon nitride 502B is patterned (Fig. 5B). Then silicon is removed (Fig. 5C) to thin the silicon substrate to about 10  $\mu\text{m}$  by KOH etching. Next (Fig. 5D) front side silicon nitride 502N is patterned to define the shadow pattern. The wafer is immersed  
25 into isotropic etchant (composed of HF, HNO<sub>3</sub>, and acetic acid with a ratio of 1:4:3) at room temperature; (Fig. 5E) the silicon membrane is etched from both of front and backside until the shadow pattern is clearly visible. To harden the shadow mask (protecting the fracture), 5  $\mu\text{m}$  thick conformal parylene film 510 is deposited (Fig. 5F).

The shadow mask is bonded with photoresist after aligning onto substrate. Then  
30 thermal evaporation is done with high deposition rate (about 50Å/sec) in order to get CVD-

**THIS PAGE BLANK (USPTO)**



like conformal deposition as shown in Fig. 4E. In this high deposition rate, the deposition pressure is  $3\text{E-}3$  torr and mean free path of the aluminum vapor atoms (1.7 cm) becomes much smaller than the distance of the source to the substrates (25 cm).

5 In addition to the above, a technique to fabricate a cantilever-like diaphragm that releases the residual stress (and also is mechanically flexible) much like a cantilever, and yet is itself a diaphragm with its four edges clamped is described. Using the high mechanical flexibility (i.e., extremely low Young's Modulus) of parylene as a holding layer, various piezoelectric acoustic transducers built on silicon nitride layer (either in cantilever form and/or freely-suspended island form) with electrodes and piezoelectric ZnO film can be  
10 fabricated. The cantilevers and island are held together by a  $1\text{ }\mu\text{m}$  thick parylene to form a flat diaphragm, similar to what is shown in Fig. 6, which shows a device comprising four cantilever structures near the edges and one floating island structure at the center.

Since parylene has a relatively low melting point (around  $280^{\circ}\text{C}$  for parylene C), a parylene holding layer is deposited toward the end of the fabrication process after  
15 processing all the high temperature steps. The contact holes are opened through the parylene layer for access to the top and bottom electrodes. Then, after releasing the diaphragm with KOH etching, the silicon nitride is patterned from the backside with a reactive ion etcher (RIE) using photoresist as a mask layer. In order to spin-coat photoresist on the backside of a wafer that has released diaphragms with large topography, the front side of the wafer  
20 can be glued onto a bare dummy wafer with a double-side tape. Then letting the dummy wafer take the vacuum pressure of the photoresist spinner, the backside of the device wafer is coated with photoresist. The dummy wafer is detached before the exposed photoresist is developed (by applying isopropyl alcohol at the tape ends). This way, the silicon nitride is successfully patterned from the backside without damaging the released diaphragms.

25 Parylene micromachined piezoelectric acoustic transducers can be fabricated on a  $1.5\text{ }\mu\text{m}$  thick flat and dome-shaped parylene diaphragm ( $5,000\text{ }\mu\text{m}^2$  for flat square diaphragm and  $2,000\text{ }\mu\text{m}$  in radius with a circular clamped boundary for dome-shaped diaphragm) with electrodes and a piezoelectric ZnO film. Parylene devices are utilized as a microphone and micro speaker.

**THIS PAGE BLANK (USPTO)**

A parylene diaphragm has about 100 times lower stiffness than silicon nitride, considerably increasing the sensitivity at audio range comparing with conventional device made by silicon nitride diaphragm.

In order to make parylene compatible with high temperature micromachining process, pre-structure process with silicon nitride has been utilized.

The parylene piezoelectric dome-shaped diaphragm has the following advantages: releasing residual stress in the diaphragm through its volumetric shrinkage or expansion, producing its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm), and increasing the figure of merit (the product of the fundamental resonant frequency squared and the dc response) based on the structural stiffness of dome so generating ultrasonic sound effectively.

To pattern the aluminum electrode on 3-dimensional structure, shadow mask method with high deposition rate thermal evaporation has been successfully used to solve the discontinuity patterning problem at a sharp boundary edge of dome-shaped diaphragm structure.

The next succeeding figures show some additional structures which can be fabricated using the processes shown in Fig. 3, and which utilize the parylene as a substrate to support one or more cantilever-shape transducers. Such cantilever-shape transducers have the advantage that they are connected to the supporting silicon substrate structure only on one side with the other sides being free to move. This puts all the stress concentrated on a single edge, so that as the transducer is flexed, it can be easier to convert these changes in shape to an electrical signal. Therefore, referring for example to the multi-cantilever design of Fig. 6, this design includes the parylene diaphragm 624 which is co-extensive with the outline of the diaphragm. In this case, four cantilever-type transducers 602 are provided, each comprising a silicon nitride layer 604 under the parylene diaphragm and, along the edge, electrode connection regions comprising the layers of silicon nitride, zinc oxide, ZnO, the top and bottom electrodes 610, 612 and an insulating layer which is shown in Figs. 1A and 2A. Electrode connectors 614, 616 provide the necessary connections to these electrode regions of each cantilever transducer. The center section also includes an SiN layer 630 which is generally rectangular in shape and partially overlying that area a silicon nitride

**THIS PAGE BLANK (USPTO)**

SiN layer 632 as well as the electrode connections 634, 636 to separate external electrodes 638, 640.

The design of Fig. 7 is similar except that no electrodes run to the center region, and there is no silicon nitride or ZnO in the center region. Rather, a coupling mass, such as aluminum, is located in the center section between the four cantilevered transducers to enhance the response to any received change in pressure.

A further alternative of course as shown in Fig. 8 would be to leave the center section completely open and covered only by a portion of the parylene diaphragm film 624 which also supports the four cantilever transducers 802, 804, 806 and 808. As can be seen, in similar fashion to Fig. 6, each of these has connecting electrodes at the one supported edge, the connecting layers being defined by SiN, ZnO, and an insulating layer between the aluminum or other electrical connecting layers.

In yet another alternative, only a single cantilever shape may be used as shown in Figs. 9A, 9B and 9C. Fig. 9A shows a rectangular transducer with a parylene layer 902 and a rectangular cantilever transducer 904 of silicon nitride and a SiN, ZnO electrode connecting layer 906 along the fastened edge. Fig. 9B is similar, except that the cantilever structure 910 is now a trapezoid in shape to provide a larger electrode connection region defined of SiN and ZnO, 912. Finally, Fig. 9C, similar to Fig. 9A, shows a rectangular cantilever transducer 920 with a reduced SiN region 922 having a series of cutouts to reduce the stiffness of the electrode region and enhance the signal delivery to the electrodes 924, 926.

Fig. 10A shows a bridge-type electrode region which comprises the layers of SiN, ZnO and electrode connections all in bridge region 911 with the silicon nitride SiN layer 914 overlapping all edges of the bridge 910. In an alternative approach, Fig. 10B, each of the ends of the bridge comprise a rectangular electrode 950, 952, 954 and 956 at each end of the bridge and comprising the SiN, ZnO layers which establish the electrical connections to external electrodes 960, 962. The center section, which is supported from a silicon nitride layer 970, and the parylene diaphragm 972 comprises the SiN, ZnO layers 974 connected to center electrodes 976, 978. A central rectangular section defined only by the parylene diaphragm layer 980 is otherwise left open to enhance the signal response.

**THIS PAGE BLANK (USPTO)**

Other features and advantages of this invention may occur to a person of skill in the art who studies this invention disclosure. Therefore, the scope of the invention is to be limited only by the following claims.

**THIS PAGE BLANK (USPTO)**



**WHAT IS CLAIMED IS:**

1. A method of fabricating a parylene diaphragm acoustic transducer comprising:  
depositing backside silicon nitride on a silicon substrate, followed by depositing  
layers of first *Al*, insulating parylene and second *Al*;  
5 depositing a second thicker parylene layer as a diaphragm;  
patterning contact holes to the bottom and top *Al* layers;  
releasing the diaphragm by patterning the backside silicon nitride; and  
removing portions the silicon substrate by etching to release the diaphragm.
2. A method as claimed in claim 1 including the further step of depositing silicon nitride  
10 on a deposition surface of the silicon substrate, and, after removing portions of the silicon  
substrate to release the diaphragm, then patterning the silicon nitride top side layer.
3. A method of fabricating a parylene diaphragm acoustic transducer comprising:  
depositing silicon nitride on a silicon substrate, followed by depositing a first  
conductive layer, an insulating layer, and a second conductive layer;  
15 depositing a zinc oxide layer adjacent the insulating layer;  
depositing a parylene layer in a form to serve as a diaphragm;  
patterning contact holes to the top and bottom conductive layers; and  
releasing the diaphragm by removing the underlying silicon substrate.
4. A method as claimed in claim 3 wherein the insulating layer is layer of parylene  
20 which is relatively thinner than the diaphragm parylene layer.
5. A method as claimed in claim 4 wherein the zinc oxide ZnO layer is deposited over  
the first conductive layer and underneath is deposited after the first conductive layer and  
prior to the insulating parylene layer.
6. A method as claimed in claim 5 including the further step of patterning the backside  
25 silicon nitride to provide further support for the parylene.

**THIS PAGE BLANK (USPTO)**

7. A method as claimed in claim 4 wherein the silicon nitride is patterned to form cantilever type transducer elements supported on a bottom surface of the parylene, and wherein the zinc oxide and electrodes are patterned to only extend along an edge of each of the cantilever style transducers.

5 8. A method as claimed in claim 7 wherein each of the silicon nitride transducer elements is in a generally trapezoidal shape and arrayed about a center region of the parylene diaphragm layer.

9. A method as claimed in claim 4 wherein the silicon nitride layer underlying the parylene diaphragm layer is patterned to form a single cantilever type transducer including  
10 a narrow region of zinc oxide and electrode contacts extending along the side of the transducer supported from the silicon substrate.

10. A method as claimed in claim 9 wherein the cantilever type silicon nitride transducer is generally rectangular in shape.

11. A method as claimed in claim 9 wherein the transducer is a single transducer formed  
15 of a layer of silicon nitride in a generally trapezoidal shape with the single zinc oxide layer extending along the edge of the transducer supported directly from the silicon substrate.

12. A parylene diaphragm acoustic transducer comprising a silicon substrate supporting first and second conducting layers, separated by an insulating layer, and having a layer of zinc oxide ZnO in between the first and second conducting layers, and a layer of parylene  
20 serving as a diaphragm layer formed over the zinc oxide layer formed at least in part over the zinc oxide layer.

13. A parylene diaphragm transducer wherein the insulating layer between the conducting layers is a thin layer of parylene and the parylene layer serving as a diaphragm is relatively thicker in extent.

**THIS PAGE BLANK (USPTO)**

14. A parylene diaphragm acoustic transducer including a silicon nitride layer underlying the parylene diaphragm layer in part, the silicon nitride layer defining in cooperation with the zinc oxide layer an acoustic transducer supported from the parylene layer.

5 15. An acoustic transducer as claimed in claim 14 wherein the silicon nitride layer is patterned to form one or more trapezoid shaped cantilever type acoustic transducers underlying the parylene layer and having the zinc oxide layer extending only along an edge of the silicon nitride layer that is directly supported from the underlying silicon substrate.

10 16. A parylene diaphragm acoustic transducer as claimed in claim 14 wherein a center region of the parylene diaphragm layer is occupied by a silicon nitride layer separate from the cantilever type silicon nitride transducer layers, and further having a zinc oxide layer at least partially overlying the silicon nitride layer and separately connected to electrode lines running to separate electrode terminals from the electrode terminals connected to the edged of the cantilever type acoustic transducers.

15 17. A parylene diaphragm acoustic transducer as defined in claim 16 further including a center region of the parylene diaphragm left blank by the cantilever type silicon nitride acoustic transducers, and having thereon a layer of aluminum to emphasize the movement of the parylene diaphragm.

20 18. A parylene diaphragm acoustic transducer as claimed in claim 14 further including a silicon nitride layer underlying the parylene diaphragm and defining a single cantilever type acoustic transducer underlying a portion of the parylene diaphragm layer, and further including the region of zinc oxide extending only along an edge of the cantilever type acoustic transducer supported from the underlying silicon substrate.

19. A parylene diaphragm acoustic transducer as claimed in claim 18 wherein the silicon nitride layer is generally rectangular in shape.

**THIS PAGE BLANK (USPTO)**

20. A parylene diaphragm acoustic transducer as claimed in claim 18 wherein the silicon nitride layer is generally trapezoidal in shape.

5 21. A parylene diaphragm acoustic transducer as claimed in claim 19 wherein the zinc oxide region extends along an edge of the acoustic transducer supported from the silicon substrate, and wherein both the zinc oxide layer and the silicon nitride layer defining the acoustic transducer are periodically interrupted extending therethrough to the parylene diaphragm layer so that the signal energy of the acoustic transducer is focused to an electrode layer connected to the supported edge thereof.

**THIS PAGE BLANK (USPTO)**



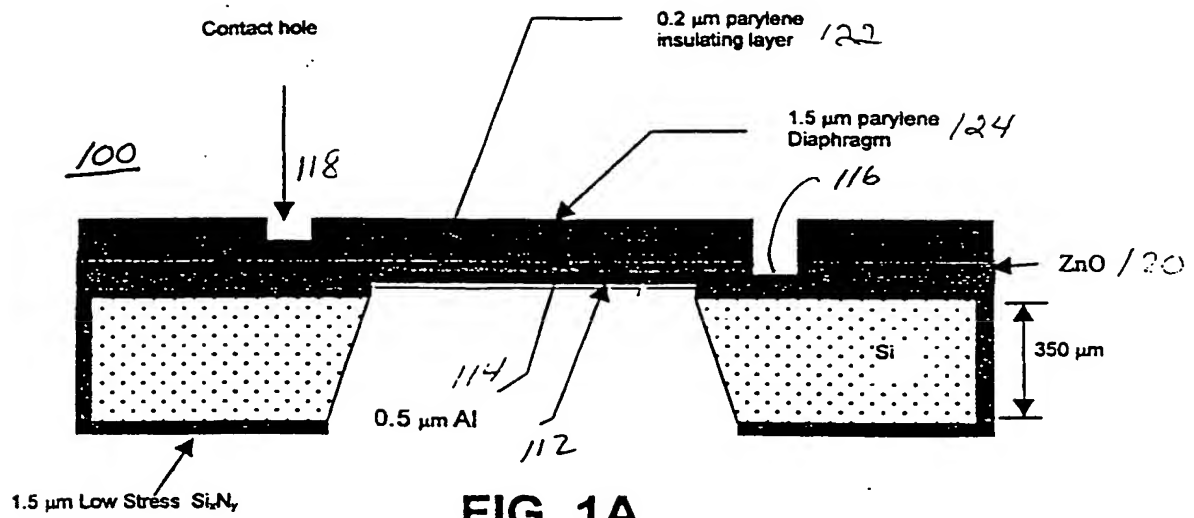


FIG. 1A

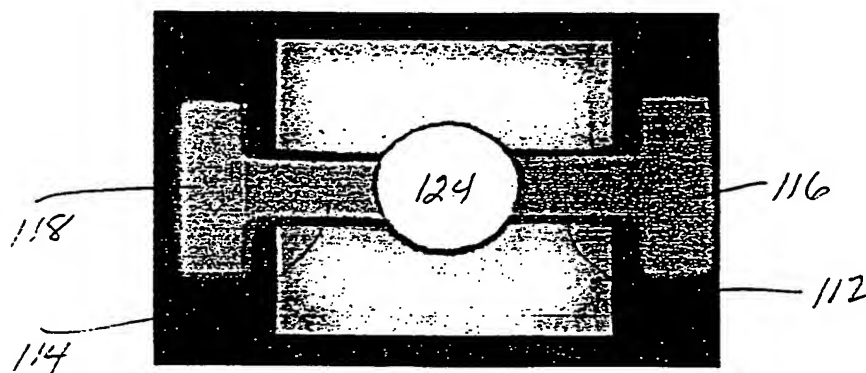


FIG. 1B

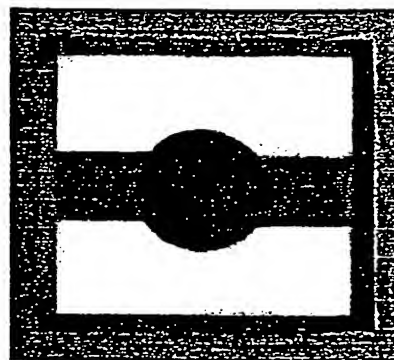


FIG. 1C

**THIS PAGE BLANK (USPTO)**

**THIS PAGE BLANK (USPTO)**

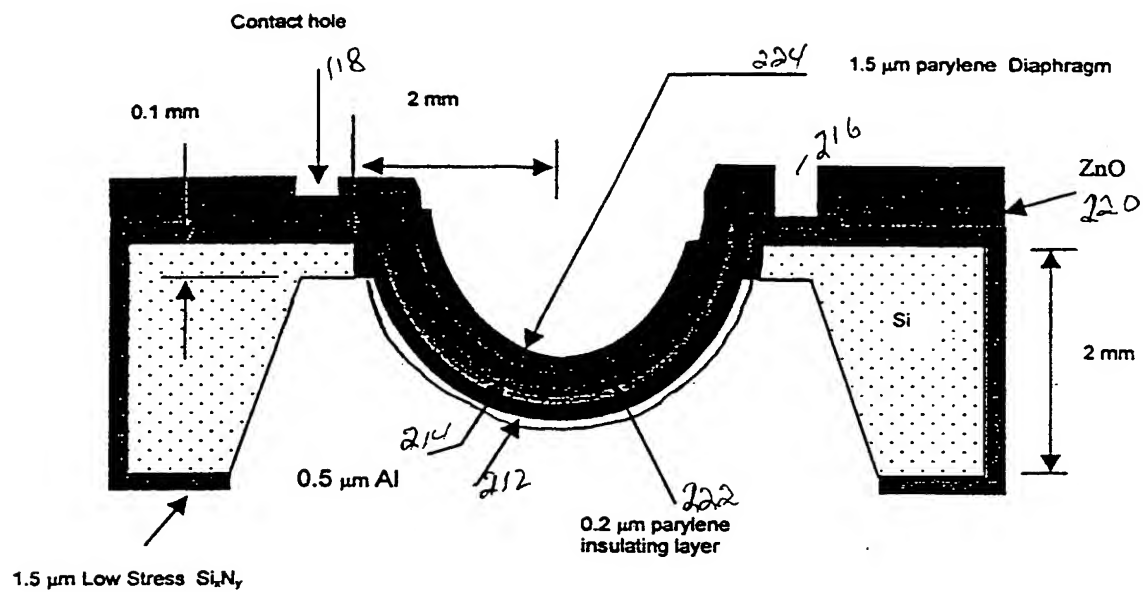


FIG. 2A

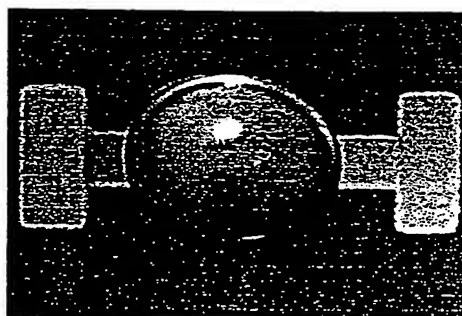


FIG. 2B

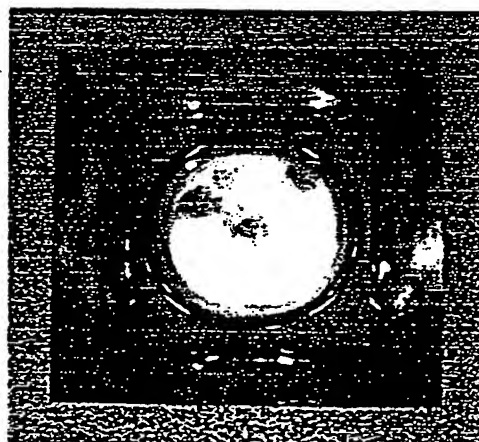
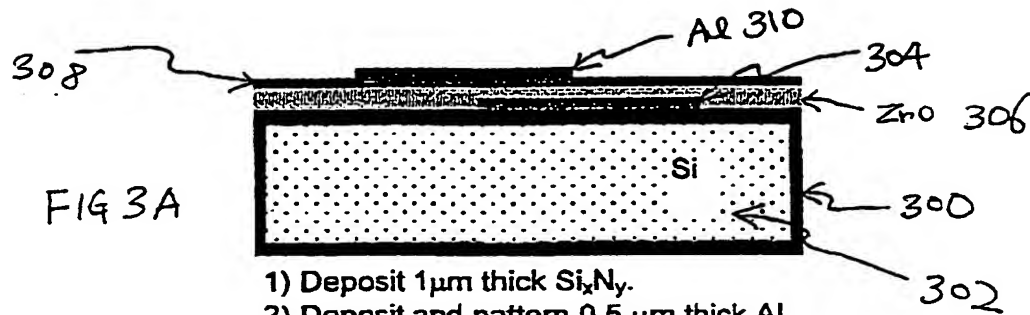
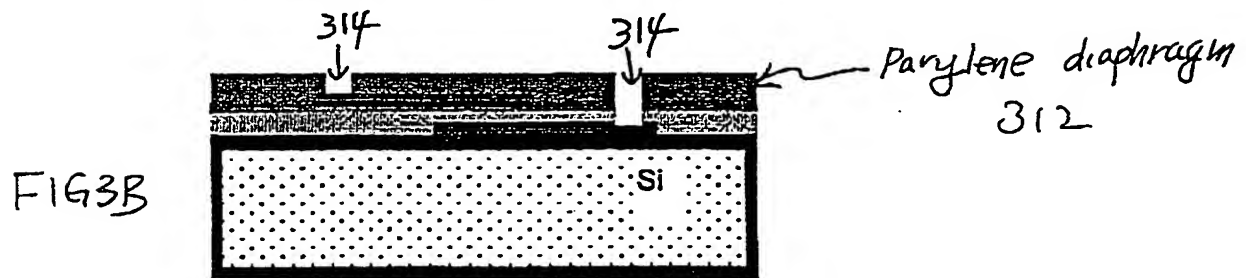


FIG. 2C

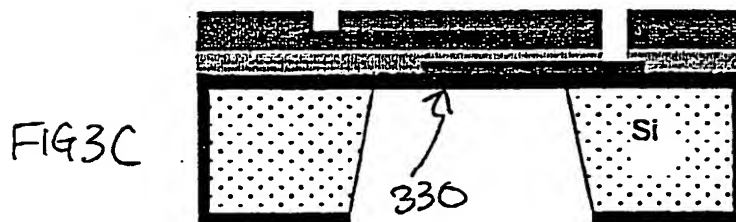
**THIS PAGE BLANK (USPTO)**



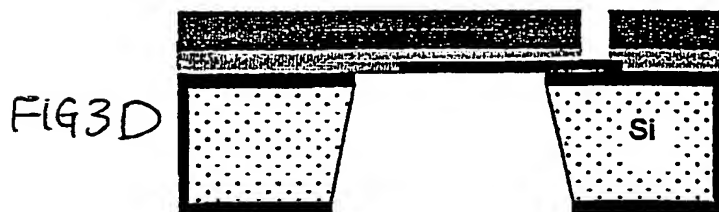
- 1) Deposit 1  $\mu\text{m}$  thick  $\text{Si}_3\text{N}_4$ .
- 2) Deposit and pattern 0.5  $\mu\text{m}$  thick Al.
- 3) Deposit 0.5  $\mu\text{m}$  thick ZnO.
- 4) Deposit 0.2  $\mu\text{m}$  thick parylene as insulator.
- 5) Deposit and pattern 0.5  $\mu\text{m}$  thick Al.



- 6) Deposit 1  $\mu\text{m}$  thick parylene.
- 7) Open contact holes.

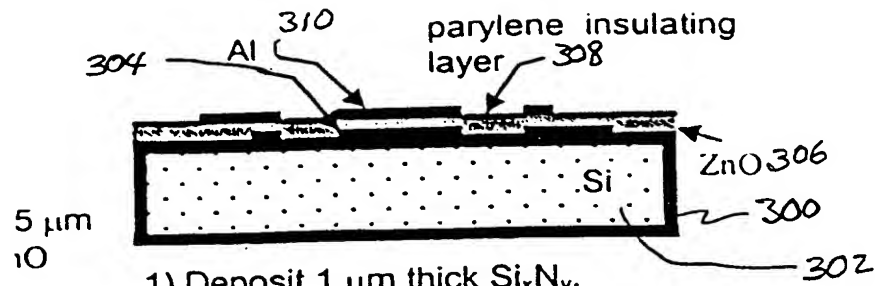


- 8) Pattern backside  $\text{Si}_3\text{N}_4$ .
- 9) Remove Si by KOH etching.



- 10) Etch bottom  $\text{Si}_3\text{N}_4$ : either completely remove it for the parylene flat-diaphragm transducer, or selectively pattern it for the parylene-held cantilever-like-diaphragm transducer.

**THIS PAGE BLANK (USPTO)**



- 1) Deposit 1  $\mu\text{m}$  thick  $\text{Si}_3\text{N}_4$ .
- 2) Deposit and pattern 0.5  $\mu\text{m}$  Al.
- 3) Deposit 0.5  $\mu\text{m}$  ZnO.
- 4) Deposit 0.2  $\mu\text{m}$  parylene.
- 5) Deposit and pattern 0.5  $\mu\text{m}$  Al.

FIG 3E

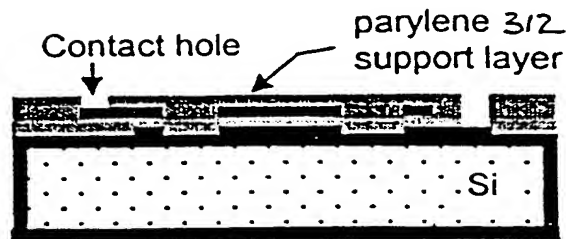


FIG 3F

- 6) Deposit 1  $\mu\text{m}$  thick parylene.
- 7) Pattern contact hole.

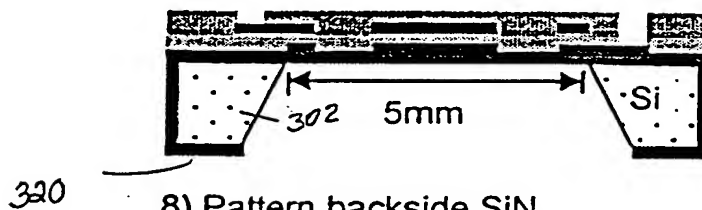


FIG 3 G

- 8) Pattern backside  $\text{SiN}$ .
- 9) Remove Si by KOH etching.

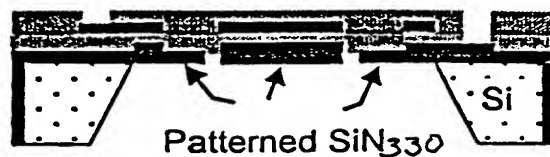
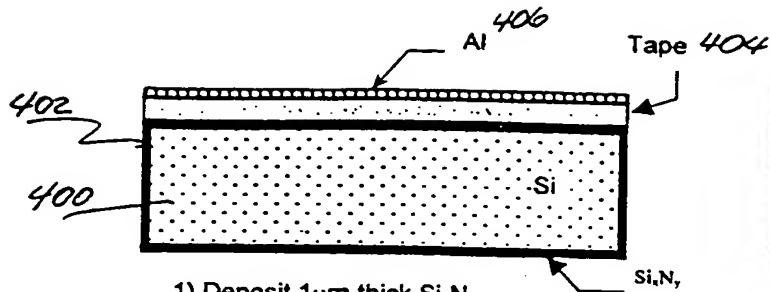


FIG. 3 H

- 10) Pattern the  $\text{SiN}$  diaphragm from the backside.

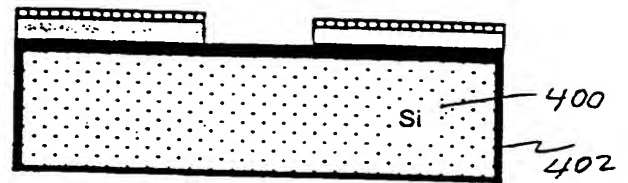
**THIS PAGE BLANK (USPTO)**





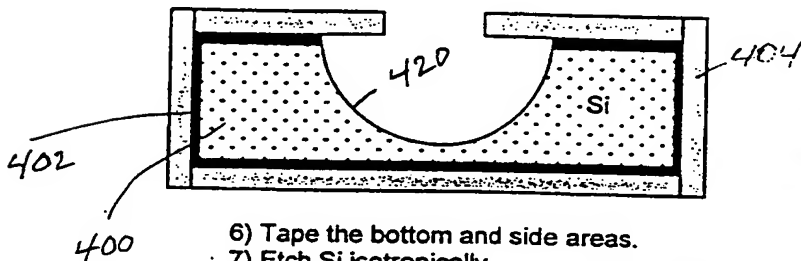
- 1) Deposit  $1\mu\text{m}$  thick  $\text{Si}_3\text{N}_4$ .
- 2) Apply  $75\mu\text{m}$  thick tape.
- 3) Deposit  $0.3\mu\text{m}$  thick Al.

FIG 4A



- 4) Pattern the Al.
- 5) Etch the tape in RIE.

FIG 4B



- 6) Tape the bottom and side areas.
- 7) Etch Si isotropically.
- 8) Remove the tape.
- 9) Do a secondary isotropic etching.
- 10) Remove the remaining  $\text{Si}_3\text{N}_4$ .

FIG 4C

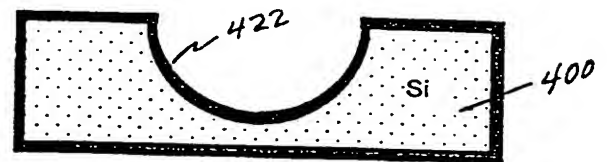
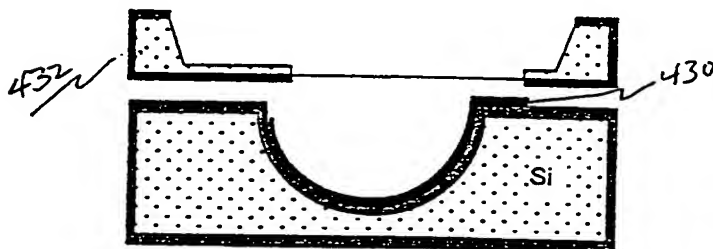


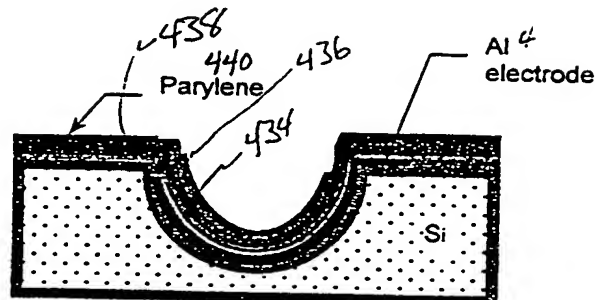
FIG 4D

- 11) Deposit  $1.5\mu\text{m}$  thick  $\text{Si}_3\text{N}_4$ .



- 12) Deposit  $0.5\mu\text{m}$  Al with thermal evaporation through a shadow mask

FIG 4E



- 13) Deposit  $0.5\mu\text{m}$  thick ZnO.
- 14) Deposit  $0.2\mu\text{m}$  thick Parylene.
- 15) Deposit  $0.5\mu\text{m}$  Al with thermal evaporation through a shadow mask
- 16) Deposit  $1.5\mu\text{m}$  thick ZnO.

FIG 4F

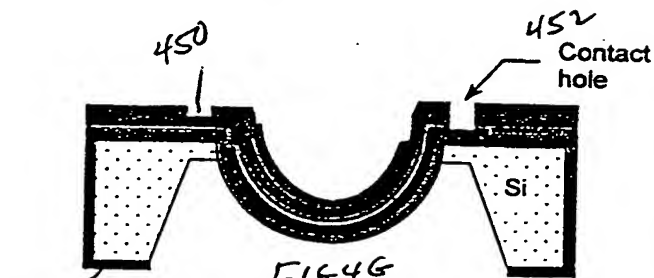


FIG 4G

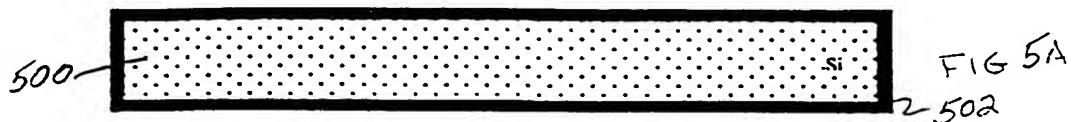
- 17) Open contact hole for both of bottom and top electrode Al.
- 18) Pattern backside  $\text{Si}_3\text{N}_4$  and release diaphragm



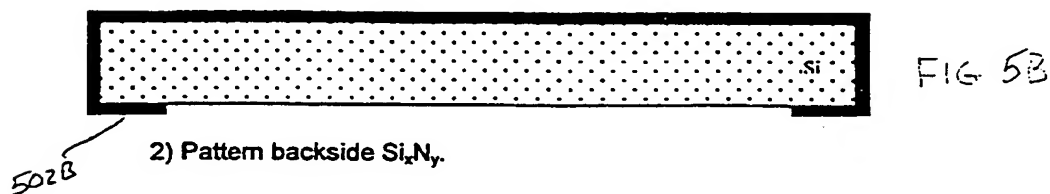
FIG 4H

- 19) Remove bottom  $\text{Si}_3\text{N}_4$  to release the parylene diaphragm

**THIS PAGE BLANK (USPTO)**



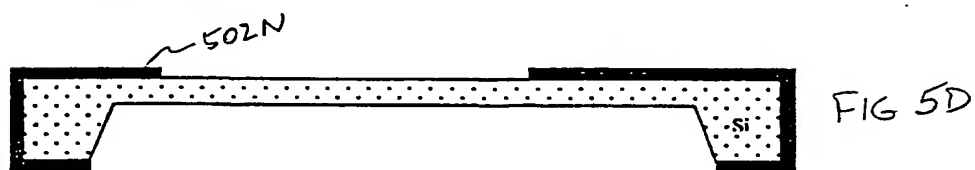
1) Deposit 1 $\mu$ m thick Si<sub>x</sub>N<sub>y</sub>.



2) Pattern backside Si<sub>x</sub>N<sub>y</sub>.



3) Remove back side Si substrate with remaining few 10s  $\mu$ m thick.



4) Pattern the front side Si<sub>x</sub>N<sub>y</sub>



5) Etch isotropically for both of front and back side to open the shadow mask hole



6) Deposit parylene conformally

**THIS PAGE BLANK (USP)**

Multi Cantilever Type

FIG 6

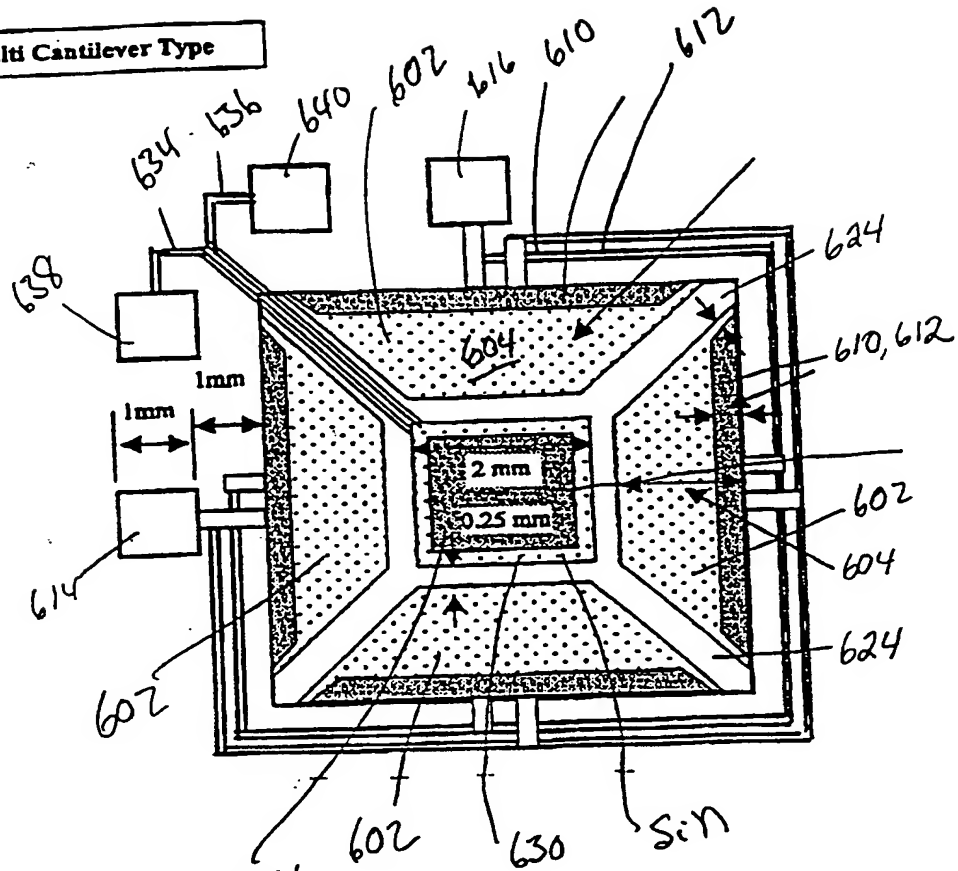
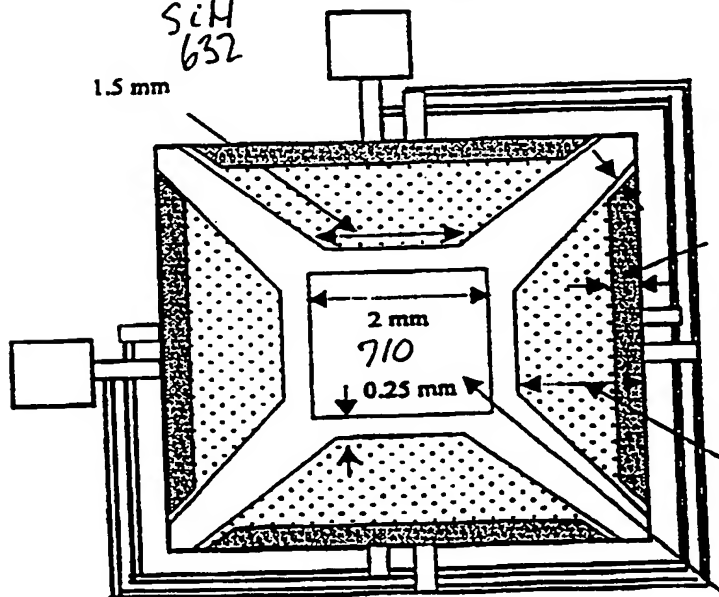
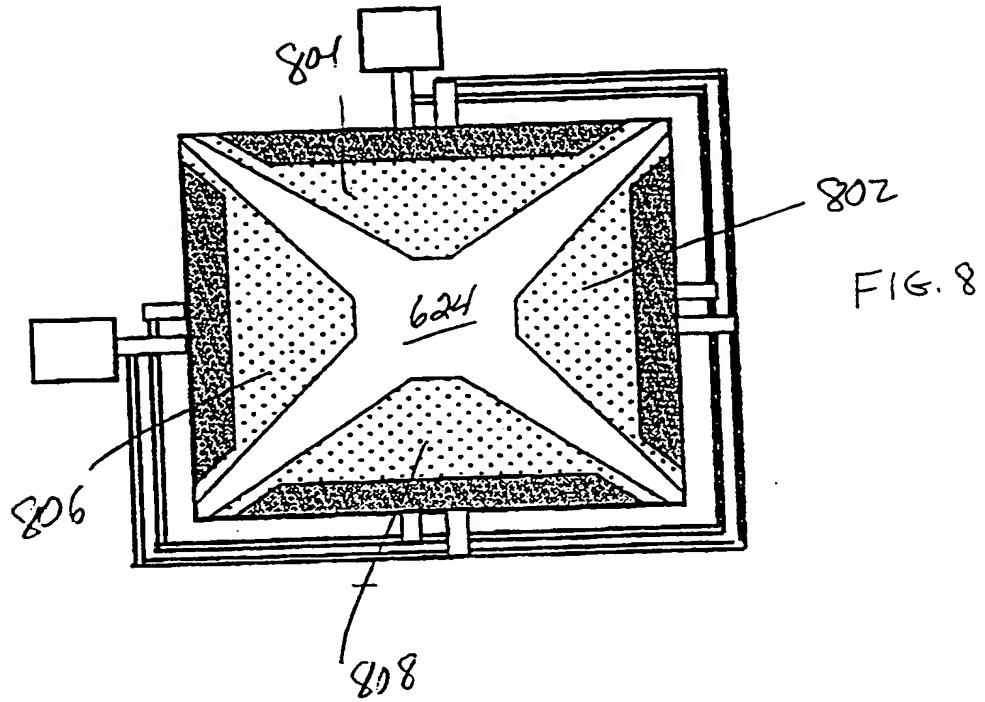


FIG 7

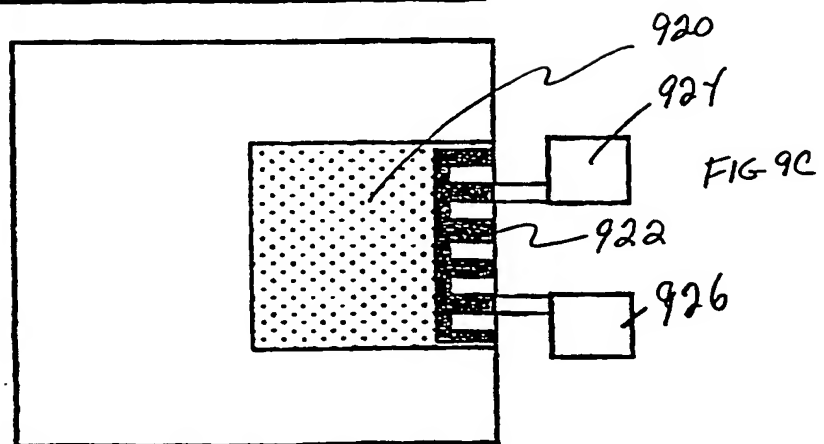
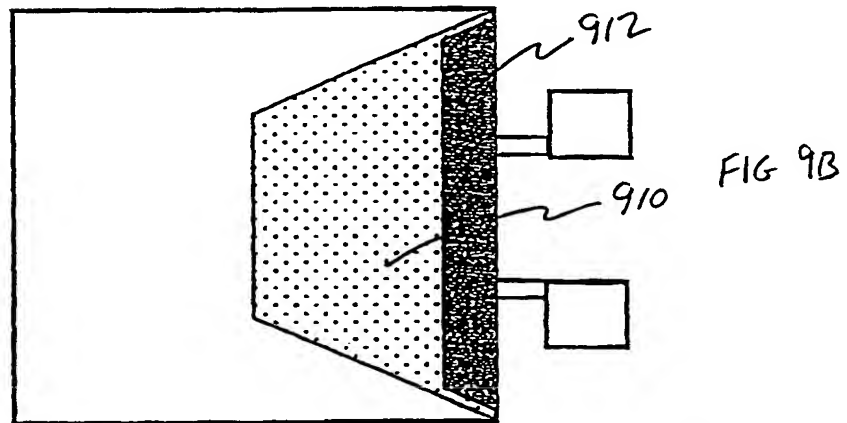
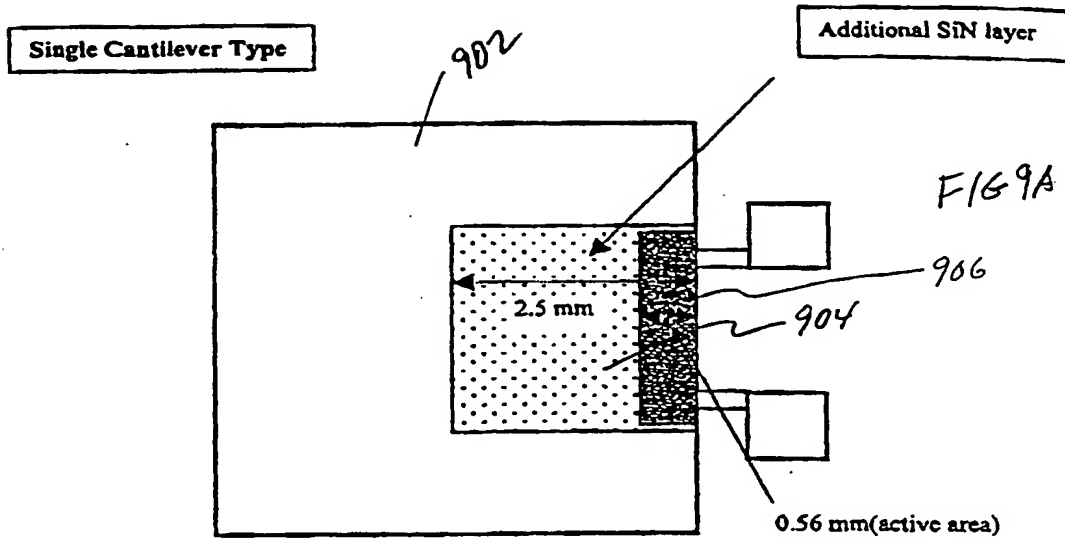


**THIS PAGE BLANK (USPTO)**



**THIS PAGE BLANK (USPTO)**





**THIS PAGE BLANK (USPTO)**

Bridge Type

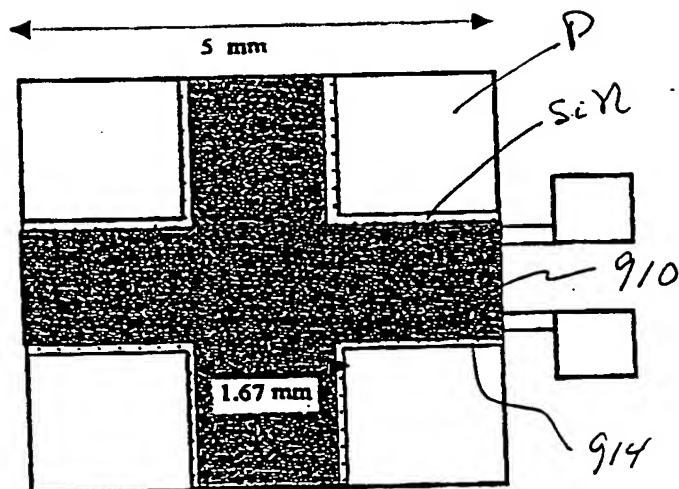


FIG 10A

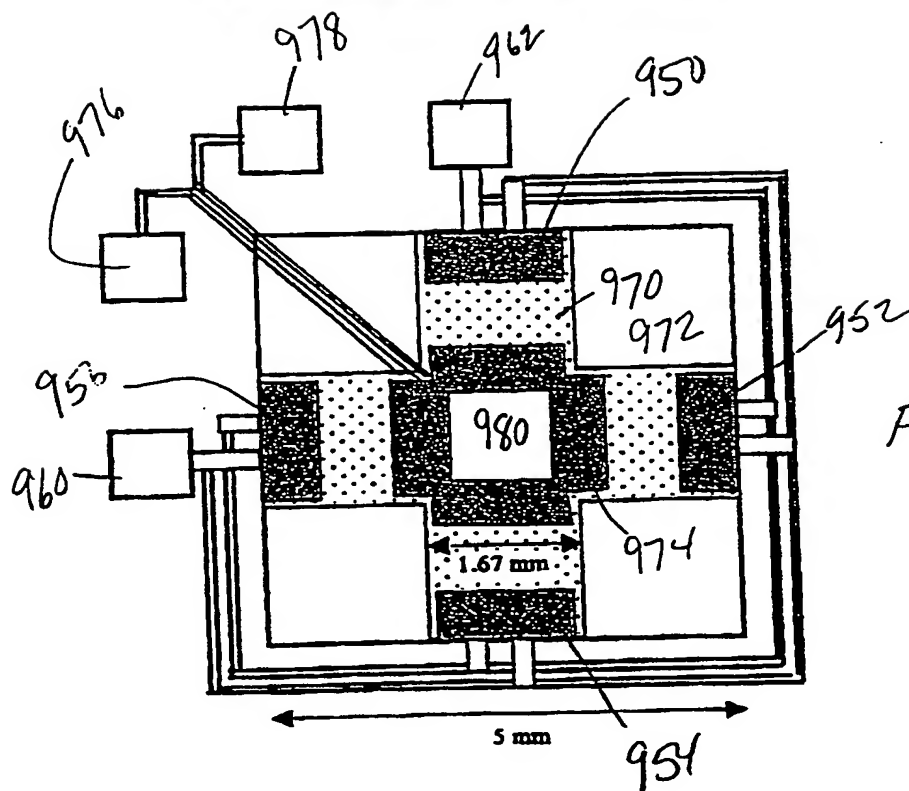


FIG 10B

**THIS PAGE BLANK (USPTO)**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/25962

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H04R 25/00, 31/00

US CL : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
WEST (USPATFULL, JPO abstracts, EPO abstracts, WPIDS, IBM TDB)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,783,821 A (MULLER et al) 08 November 1988 (08.11.1988), column 2, lines 6-34.	1-21
Y	US 5,209,118 A (JERMAN) 11 May 1993 (11.05.1993), column 6, line 65-column 7, line 8.	1-21
Y	US 5,490,220 A (LOEPPERT) 06 February 1996 (06.02.1996), column 4, lines 47-64).	6-11, 14-21
A	US 4,607,145 A (RAVINET et al) 19 August 1986 (19.08.1986), column 2, lines 50-53.	
A	US 5,870,351 A (LADABAUM et al) 09 February 1999 (09.02.1999), column 4, lines 51-59.	
A	US 5,479,061 A (BOBBIO et al) 26 December 1995 (26.12.1995).	
A	WO 99/24744 A1 (CALIFORNIA INSTITUTE OF TECHNOLOGY) 20 May 1999 (20.05.1999).	

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

### \* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

07 December 2000 (07.12.2000)

Date of mailing of the international search report

29 DEC 2000

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703)305-3230

Authorized officer

Anita Alanko

Telephone No. 703-308-0661

Jean Proctor  
Paralegal Specialist

**THIS PAGE BLANK (USPTO)**

CORRECTED VERSION

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
29 March 2001 (29.03.2001)

PCT

(10) International Publication Number  
WO 01/022776 A1

(51) International Patent Classification<sup>7</sup>: H04R 25/00, 31/00

(21) International Application Number: PCT/US00/25962

(22) International Filing Date:  
21 September 2000 (21.09.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
60/155,045 21 September 1999 (21.09.1999) US

(71) Applicant (for all designated States except US): UNIVERSITY OF HAWAII [US/US]; 2800 Woodlawn Drive, Suite 280, Honolulu, HI 96822 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): HAN, Cheol-Hyun [KR/US]; 2724 Kaloaloha Ln. #1403, Honolulu, HI 96826 (US). KIM, Eun, Sok [US/US]; 4461 PCH #C104, Torrance, CA 90505 (US).

(74) Agents: SWIATEK, Maria, S. et al.; Flehr Hobbach Test Albritton & Herbert LLP, 4 Embarcadero Center, Suite 3400, San Francisco, CA 94111-4187 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SE, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, NL, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, EE, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

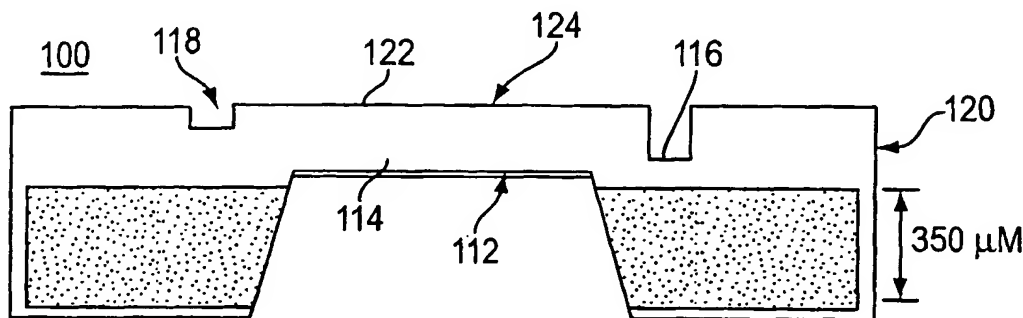
— with international search report

(48) Date of publication of this corrected version:  
5 December 2002

(15) Information about Correction:  
see PCT Gazette No. 49/2002 of 5 December 2002, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS



(57) Abstract: A micromachined acoustic transducer (100) comprising a parylene diaphragm (124) piezoelectric transducer. The parylene diaphragm has far lower stiffness than silicon nitride. The method for fabricating the parylene diaphragm acoustic transducer utilizes a prestructured diaphragm layer utilizing silicon nitride which is compatible with high temperature semiconductor processing. A silicon nitride layer is patterned and partially removed after forming the parylene diaphragm layer in order to enhance the structural qualities of the parylene diaphragm. The diaphragm may be flat or dome-shaped.

WO 01/022776 A1

**THIS PAGE BLANK (USPTO)**



## METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS

### Cross-Reference to a Related Application

The present application is based on a provisional application Serial No. 60/155,045 filed September 21, 1999, and entitled METHOD OF FORMING PARYLENE-DIAPHRAGM PIEZOELECTRIC ACOUSTIC TRANSDUCERS; this provisional application is incorporated herein by reference, and the priority of the provisional application is claimed herein.

### Field of the Invention

The present invention relates to the micromachined acoustic transducers and their fabrication technology. More particularly this invention relates to parylene-diaphragm piezoelectric acoustic transducers on flat and dome-shaped diaphragm in silicon substrate.

### Background of the Invention

Recently, there has been increasing interest in micromachined acoustic transducers based on the following advantages: size miniaturization with extremely small weight, potentially low cost due to the batch processing, possibility of integrating transducers and circuits on a single chip, lack of transducer "ringing" due to small diaphragm mass. Especially, these advantages make the micromachined acoustic transducers, such as microphone and micro speaker, attractive in the applications for personal communication systems, multimedia systems, hearing aids and so on.

Micromachined acoustic transducers are provided with a thin diaphragm and several diaphragm materials that must be compatible with high temperature semiconductor process,

such as silicon nitride and silicon have been utilized as diaphragm. However, micromachined acoustic transducers made by these conventional diaphragm materials suffer from a relatively low sensitivity and it is mainly because of the high stiffness and residual stress of these diaphragm materials.

5 In order to implement the micromachined acoustic transducers with competitive performance with conventional acoustic transducers, it is necessary to find new diaphragm materials that have low stiffness and compatibility with semiconductor processing at the same time. Also, the transducer should be designed to release or minimize the residual stress of the diaphragm.

#### 10 Summary of the Invention

The present invention relates to piezoelectric acoustic transducers and improved methods of making such transducers.

15 In accordance with one embodiment of the invention, the piezoelectric transducer is made of parylene; in accordance with a further embodiment of the invention, the parylene diaphragm is supported by a patterned silicon nitride layer.

In accordance with a further aspect of the invention, the diaphragm is made in accordance with a process utilizing a silicon nitride diaphragm layer which is compatible with high temperature semiconductor processing.

20 In summary, the present invention comprises a micromachined acoustic transducer comprising a parylene-diaphragm piezoelectric transducer. The parylene diaphragm has far lower stiffness than silicon nitride which has been the dominant technology for micromachined diaphragms, and provides higher performing acoustic devices. The parylene diaphragm is almost free from the residual stress problem, and considerably reduces  
25 transducer sensitivity.

The invention further comprises a method for fabricating the parylene diaphragm acoustic transducer utilizing a prestructured diaphragm layer utilizing silicon nitride which is compatible with high temperature semiconductor process.

30 In a preferred embodiment, the silicon nitride layer is patterned and partially removed after forming the parylene diaphragm layer in order to enhance the structural qualities of the parylene diaphragm.

In a further refinement of the process, a shadow masking technique utilizing high deposition rate thermal evaporation for conformal deposition of a metal electrode on a dome-shaped parylene diaphragm is utilized.

5 In an especially preferred embodiment, the parylene diaphragm acoustic transducer is a dome-shaped diaphragm which especially provides the following advantages:

- (1) a dome diaphragm releases residual stress in the diaphragm through its volumetric shrinking or expansion;
- (2) a dome diaphragm piezoelectric transducer produces its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm);
- 10 (3) a dome diaphragm transducer has a higher figure of merit (the product of the fundamental resonant frequency squared and the dc response) than a flat diaphragm based transducer.

Other features and advantages of the invention will become apparent to a person of skill in the art who studies the following description of the preferred and exemplary embodiments, given in association with the following figures.

#### Brief Description of the Drawings

FIG. 1A is a cross-sectional view drawing of the parylene piezoelectric flat diaphragm acoustic transducer;

20 FIG. 1B is a top view photo of a fabricated parylene flat diaphragm acoustic transducer;

FIG. 1C is a bottom view photo of the parylene flat diaphragm acoustic transducer;

FIG. 2A is a cross-sectional view drawing of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

25 FIG. 2B is a top view photo of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

FIG. 2C is a bottom view photo of the parylene piezoelectric dome-shaped diaphragm acoustic transducer;

30 FIGS. 3A-3H are the processing steps to fabricate the parylene flat-diaphragm acoustic transducers and the parylene-held cantilever-like-diaphragm acoustic transducers;

FIGS. 4A-4H show the processing steps to fabricate the parylene piezoelectric dome-shaped diaphragm acoustic transducer with the shadow-mask patterning method;

FIGS. 5A-5F show the processing steps to fabricate the shadow mask using anisotropic and isotropic etching technique;

5           FIGS. 6, 7, 8, 9A-9C and 10A-10B illustrate various cantilever type parylene diaphragm acoustic transducers which can be fabricated using the technology described above.

#### Detailed Description of the Invention

10           Microelectromechanical Systems (MEMS) technology has been used to fabricate tiny microphones and microspeakers on a silicon wafer. This method of fabricating acoustic transducers on a silicon wafer has the following advantages over the more traditional methods: potentially low cost due to the batch processing, possibility of integrating sensor and amplifier on a single chip, and size miniaturization. Furthermore, a thin-diaphragm-based miniature acoustic transducer has low vibration sensitivity due to the small diaphragm mass.

15           Compared to more popular condenser-type MEMS microphones, piezoelectric MEMS microphones are simpler to fabricate, free from any polarization-voltage requirement, and responsive over a wider dynamic range. However, a piezoelectric MEMS microphone suffers from a relatively low sensitivity, mainly due to high stiffness of the diaphragm materials used for the microphone. The thin film materials currently used for a diaphragm such as silicon nitride, silicon, and polysilicon were adopted because they are compatible with semiconductor processing techniques; but these materials have high stiffness and residual stress. High temperature semiconductor processing hinders the usage of more flexible materials such as polymer films as diaphragm materials, though many conventional bulky acoustic transducers use polymer diaphragm to improve the performance.

20           As a new approach for building micromachined acoustic transducers, parylene micromachined piezoelectric acoustic transducers are proposed. A parylene diaphragm that has about 100 times lower stiffness than silicon nitride, considerably increases the sensitivity at audio range compared with that of a conventional device made by silicon nitride

diaphragm. Also, the parylene diaphragm is almost free of the residual stress problem which considerably reduces the sensitivity of prior art transducers.

Although parylene could be fabricated in either a flat or dome shape, a parylene piezoelectric dome-shaped diaphragm is especially useful, as it has the following advantages:

5 it releases residual stress in the diaphragm through its volumetric shrinkage or expansion; it produces its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm); and it has a higher figure of merit (the product of the fundamental resonant frequency squared and the dc response) than a flat diaphragm transducer. Therefore it generates ultrasonic sound effectively.

## 10 FABRICATION

### *A. Parylene flat diaphragm acoustic transducer*

A schematic of the process flow for the parylene micromachined piezoelectric flat diaphragm acoustic transducer (illustrated in Figs. 1A-1C) is shown in Fig. 3. First, 1  $\mu\text{m}$  thick low stress silicon nitride 300 is deposited by low pressure chemical vapor deposition (LPCVD) on a bare silicon substrate 302, followed by depositions of 0.5  $\mu\text{m}$  thick bottom Al 304, 0.5  $\mu\text{m}$  thick ZnO 306, 0.2  $\mu\text{m}$  thick parylene 308, and 0.5  $\mu\text{m}$  thick top Al 310. Then 1.5  $\mu\text{m}$  thick parylene 312 is deposited as a diaphragm. Contact holes 314 are patterned through bottom and top electrode 304, 310 which are provided by the Al. To release the diaphragm structure, backside silicon nitride 320 is patterned, and silicon substrate 302 is removed by KOH etching. Finally, the silicon nitride 330 most bottom layer of diaphragm structure is either completely removed for the parylene flat-diaphragm acoustic transducers or selectively patterned for the parylene-held cantilever-like-diaphragm acoustic transducers.

15  
20

The completed transducer 100 is shown in Figs. 1A-1C. Fig. 1A shows the layers of the transducer in cross-section, including the Al contact layers 112, 114 to contact 116, 118; the ZnO layer 120 which is provided to establish the desired transducer function; the thin insulating parylene layer 122 which separates the electrodes; and the parylene diaphragm layer 124. Several of these layers also appear in Figs. 1B and 1C, top and bottom views, respectively.

25

The parylene-held cantilever-like-diaphragm transducer formed by selectively patterning bottom  $\text{Si}_x\text{N}_y$  appears especially in Figs. 3E-3H.

*B. Parylene dome-shaped diaphragm acoustic transducer*

A schematic of the process flow for the parylene micromachined piezoelectric dome-shaped diaphragm acoustic transducer is 200 which is shown in Figs. 2A-2C is shown in Fig. 4. First, 1  $\mu\text{m}$  thick low stress silicon nitride 402 is deposited by low pressure chemical vapor deposition (LPCVD) on a bare silicon substrate 400 to prevent any possible contamination from the polyethylene tape used in subsequent processing steps. Also, this silicon nitride layer 402 functions as an etch mask in during a secondary isotropic etch of the silicon substrate (which is a step to improve the etch-front circularity and smoothness simultaneously). A polyethylene tape 404 is then pasted on the silicon nitride 402, and patterned in a reactive ion etcher (RIE) with Oxygen plasma (in this RIE step, Al 406 is used as an etch mask). After patterning the tape (Fig. 4B), the Al film is removed by an Al etchant (1g KOH: 10g  $\text{K}_3\text{Fe}(\text{CN})_6$ : 100ml DI water) which rarely deteriorates the tape adhesion. Tape is then used to cover the bottom and side areas. Then the silicon 400 is etched (Fig 4C) in an isotropic silicon etchant to form spherical etch fronts, followed by dissolving the polyethylene tape 404 in toluene. The etching may be performed in a Teflon beaker (without any agitation for uniform etch-stop effect) which is placed in a 50°C water bath.

An additional isotropic etching after removing the polyethylene tape (Step 9) may be needed to improve the circularity and surface roughness of the etch front which is to serve as a mold to define the dome diaphragm. After obtaining the dome-shaped etch cavity, 1.5  $\mu\text{m}$  thick slightly-compressive silicon nitride 422 is deposited on the wafer. Then a 0.5  $\mu\text{m}$  thick bottom Al 430 is deposited with thermal evaporation by using shadow mask technique illustrated by mask 432 (Fig. 4E). This is followed by 0.5  $\mu\text{m}$  thick ZnO 434, 0.2  $\mu\text{m}$  thick parylene 436, and 0.5  $\mu\text{m}$  thick top Al 438 deposited (Fig. 4F) with thermal evaporation by using shadow mask technique again. Then 1.5  $\mu\text{m}$  thick parylene 440 is deposited as parylene diaphragm layer. Next contact holes 450, 452 (Fig. 4B) are patterned through bottom and top aluminum electrode. To release the diaphragm structure (Fig. 4H), silicon substrate 400 is removed by KOH etching after backside silicon is patterned. Finally,

the silicon nitride most bottom layer 422 of diaphragm structure is either completely removed for the parylene flat-diaphragm transducers or selectively patterned for the parylene-held cantilever-like-diaphragm transducers.

5 The sequence of layers is the same as explained in Fig. 1A, including patterned SiN 210; Al contact layers 112, 114 leading to contacts 116, 118; ZnO layer 120; thin parylene insulating layer 122; and parylene diaphragm layer 224.

#### SHADOW MASK TECHNIQUE WITH HIGH DEPOSITION RATE THERMAL EVAPORATION

10 In order to get high resolution patterning in dome-shaped diaphragm and avoid disconnection problem of electrodes at a sharp edge boundary, a shadow mask technique with high deposition-rate thermal evaporation has been developed.

High resolution patterning in non-planar substrate surfaces is an often-encountered problem in a micromachined process. It is because that conventional patterning method with spin coating of photoresist can not be used. Even if conformal photoresist coating method, such as PEPR2400, is used, the patterning should be limited by the step angle of substrate surface. That is, sharp edges are still hard to pattern because the effective thickness of photoresist is too thick and the light source does not penetrate underneath photoresist.

20 The shadow mask of Fig. 5 is made of a <100> oriented 3-inch silicon wafer 600. Fig. 5 illustrates the fabrication steps of the shadow mask using anisotropic and isotropic etching. First, 1  $\mu\text{m}$  silicon nitride 502 is deposited (Fig. 5A) on the silicon substrate 500 and the backside silicon nitride 502B is patterned (Fig. 5B). Then silicon is removed (Fig. 5C) to thin the silicon substrate to about 10  $\mu\text{m}$  by KOH etching. Next (Fig. 5D) front side silicon nitride 502N is patterned to define the shadow pattern. The wafer is immersed into isotropic etchant (composed of HF, HNO<sub>3</sub>, and acetic acid with a ratio of 1:4:3) at room temperature; (Fig. 5E) the silicon membrane is etched from both of front and backside until the shadow pattern is clearly visible. To harden the shadow mask (protecting the fracture), 5  $\mu\text{m}$  thick conformal parylene film 510 is deposited (Fig. 5F).

30 The shadow mask is bonded with photoresist after aligning onto substrate. Then thermal evaporation is done with high deposition rate (about 50A/sec) in order to get CVD-

like conformal deposition as shown in Fig. 4E. In this high deposition rate, the deposition pressure is  $3\text{E-}3$  torr and mean free path of the aluminum vapor atoms (1.7 cm) becomes much smaller than the distance of the source to the substrates (25 cm).

5 In addition to the above, a technique to fabricate a cantilever-like diaphragm that releases the residual stress (and also is mechanically flexible) much like a cantilever, and yet is itself a diaphragm with its four edges clamped is described. Using the high mechanical flexibility (i.e., extremely low Young's Modulus) of parylene as a holding layer, various piezoelectric acoustic transducers built on silicon nitride layer (either in cantilever form and/or freely-suspended island form) with electrodes and piezoelectric ZnO film can be  
10 fabricated. The cantilevers and island are held together by a  $1\text{ }\mu\text{m}$  thick parylene to form a flat diaphragm, similar to what is shown in Fig. 6, which shows a device comprising four cantilever structures near the edges and one floating island structure at the center.

Since parylene has a relatively low melting point (around  $280^{\circ}\text{C}$  for parylene C), a parylene holding layer is deposited toward the end of the fabrication process after  
15 processing all the high temperature steps. The contact holes are opened through the parylene layer for access to the top and bottom electrodes. Then, after releasing the diaphragm with KOH etching, the silicon nitride is patterned from the backside with a reactive ion etcher (RIE) using photoresist as a mask layer. In order to spin-coat photoresist on the backside of a wafer that has released diaphragms with large topography, the front side of the wafer  
20 can be glued onto a bare dummy wafer with a double-side tape. Then letting the dummy wafer take the vacuum pressure of the photoresist spinner, the backside of the device wafer is coated with photoresist. The dummy wafer is detached before the exposed photoresist is developed (by applying isopropyl alcohol at the tape ends). This way, the silicon nitride is successfully patterned from the backside without damaging the released diaphragms.

25 Parylene micromachined piezoelectric acoustic transducers can be fabricated on a  $1.5\text{ }\mu\text{m}$  thick flat and dome-shaped parylene diaphragm ( $5,000\text{ }\mu\text{m}^2$  for flat square diaphragm and  $2,000\text{ }\mu\text{m}$  in radius with a circular clamped boundary for dome-shaped diaphragm) with electrodes and a piezoelectric ZnO film. Parylene devices are utilized as a microphone and micro speaker.



A parylene diaphragm has about 100 times lower stiffness than silicon nitride, considerably increasing the sensitivity at audio range comparing with conventional device made by silicon nitride diaphragm.

5 In order to make parylene compatible with high temperature micromachining process, pre-structure process with silicon nitride has been utilized.

The parylene piezoelectric dome-shaped diaphragm has the following advantages: releasing residual stress in the diaphragm through its volumetric shrinkage or expansion, producing its flexural vibration effectively from an in-plane strain (produced by a piezoelectric film sitting on a dome diaphragm), and increasing the figure of merit (the  
10 product of the fundamental resonant frequency squared and the dc response) based on the structural stiffness of dome so generating ultrasonic sound effectively.

To pattern the aluminum electrode on 3-dimensional structure, shadow mask method with high deposition rate thermal evaporation has been successfully used to solve the discontinuity patterning problem at a sharp boundary edge of dome-shaped diaphragm  
15 structure.

The next succeeding figures show some additional structures which can be fabricated using the processes shown in Fig. 3, and which utilize the parylene as a substrate to support one or more cantilever-shape transducers. Such cantilever-shape transducers have the advantage that they are connected to the supporting silicon substrate structure only on one  
20 side with the other sides being free to move. This puts all the stress concentrated on a single edge, so that as the transducer is flexed, it can be easier to convert these changes in shape to an electrical signal. Therefore, referring for example to the multi-cantilever design of Fig. 6, this design includes the parylene diaphragm 624 which is co-extensive with the outline of the diaphragm. In this case, four cantilever-type transducers 602 are provided, each  
25 comprising a silicon nitride layer 604 under the parylene diaphragm and, along the edge, electrode connection regions comprising the layers of silicon nitride, zinc oxide, ZnO, the top and bottom electrodes 610, 612 and an insulating layer which is shown in Figs. 1A and 2A. Electrode connectors 614, 616 provide the necessary connections to these electrode regions of each cantilever transducer. The center section also includes an SiN layer 630  
30 which is generally rectangular in shape and partially overlying that area a silicon nitride

SiN layer 632 as well as the electrode connections 634, 636 to separate external electrodes 638, 640.

The design of Fig. 7 is similar except that no electrodes run to the center region, and there is no silicon nitride or ZnO in the center region. Rather, a coupling mass, such as aluminum, is located in the center section between the four cantilevered transducers to enhance the response to any received change in pressure.

A further alternative of course as shown in Fig. 8 would be to leave the center section completely open and covered only by a portion of the parylene diaphragm film 624 which also supports the four cantilever transducers 802, 804, 806 and 808. As can be seen, in similar fashion to Fig. 6, each of these has connecting electrodes at the one supported edge, the connecting layers being defined by SiN, ZnO, and an insulating layer between the aluminum or other electrical connecting layers.

In yet another alternative, only a single cantilever shape may be used as shown in Figs. 9A, 9B and 9C. Fig. 9A shows a rectangular transducer with a parylene layer 902 and a rectangular cantilever transducer 904 of silicon nitride and a SiN, ZnO electrode connecting layer 906 along the fastened edge. Fig. 9B is similar, except that the cantilever structure 910 is now a trapezoid in shape to provide a larger electrode connection region defined of SiN and ZnO, 912. Finally, Fig. 9C, similar to Fig. 9A, shows a rectangular cantilever transducer 920 with a reduced SiN region 922 having a series of cutouts to reduce the stiffness of the electrode region and enhance the signal delivery to the electrodes 924, 926.

Fig. 10A shows a bridge-type electrode region which comprises the layers of SiN, ZnO and electrode connections all in bridge region 911 with the silicon nitride SiN layer 914 overlapping all edges of the bridge 910. In an alternative approach, Fig. 10B, each of the ends of the bridge comprise a rectangular electrode 950, 952, 954 and 956 at each end of the bridge and comprising the SiN, ZnO layers which establish the electrical connections to external electrodes 960, 962. The center section, which is supported from a silicon nitride layer 970, and the parylene diaphragm 972 comprises the SiN, ZnO layers 974 connected to center electrodes 976, 978. A central rectangular section defined only by the parylene diaphragm layer 980 is otherwise left open to enhance the signal response.

Other features and advantages of this invention may occur to a person of skill in the art who studies this invention disclosure. Therefore, the scope of the invention is to be limited only by the following claims.

**WHAT IS CLAIMED IS:**

1. A method of fabricating a parylene diaphragm acoustic transducer comprising:  
depositing backside silicon nitride on a silicon substrate, followed by depositing  
layers of first *Al*, insulating parylene and second *Al*;  
5 depositing a second thicker parylene layer as a diaphragm;  
patterning contact holes to the bottom and top *Al* layers;  
releasing the diaphragm by patterning the backside silicon nitride; and  
removing portions the silicon substrate by etching to release the diaphragm.
2. A method as claimed in claim 1 including the further step of depositing silicon nitride  
10 on a deposition surface of the silicon substrate, and, after removing portions of the silicon  
substrate to release the diaphragm, then patterning the silicon nitride top side layer.
3. A method of fabricating a parylene diaphragm acoustic transducer comprising:  
depositing silicon nitride on a silicon substrate, followed by depositing a first  
conductive layer, an insulating layer, and a second conductive layer;  
15 depositing a zinc oxide layer adjacent the insulating layer;  
depositing a parylene layer in a form to serve as a diaphragm;  
patterning contact holes to the top and bottom conductive layers; and  
releasing the diaphragm by removing the underlying silicon substrate.
4. A method as claimed in claim 3 wherein the insulating layer is layer of parylene  
20 which is relatively thinner than the diaphragm parylene layer.
5. A method as claimed in claim 4 wherein the zinc oxide ZnO layer is deposited over  
the first conductive layer and underneath is deposited after the first conductive layer and  
prior to the insulating parylene layer.
6. A method as claimed in claim 5 including the further step of patterning the backside  
25 silicon nitride to provide further support for the parylene.

7. A method as claimed in claim 4 wherein the silicon nitride is patterned to form cantilever type transducer elements supported on a bottom surface of the parylene, and wherein the zinc oxide and electrodes are patterned to only extend along an edge of each of the cantilever style transducers.
- 5 8. A method as claimed in claim 7 wherein each of the silicon nitride transducer elements is in a generally trapezoidal shape and arrayed about a center region of the parylene diaphragm layer.
9. A method as claimed in claim 4 wherein the silicon nitride layer underlying the parylene diaphragm layer is patterned to form a single cantilever type transducer including  
10 a narrow region of zinc oxide and electrode contacts extending along the side of the transducer supported from the silicon substrate.
10. A method as claimed in claim 9 wherein the cantilever type silicon nitride transducer is generally rectangular in shape.
11. A method as claimed in claim 9 wherein the transducer is a single transducer formed  
15 of a layer of silicon nitride in a generally trapezoidal shape with the single zinc oxide layer extending along the edge of the transducer supported directly from the silicon substrate.
12. A parylene diaphragm acoustic transducer comprising a silicon substrate supporting first and second conducting layers, separated by an insulating layer, and having a layer of zinc oxide ZnO in between the first and second conducting layers, and a layer of parylene  
20 serving as a diaphragm layer formed over the zinc oxide layer formed at least in part over the zinc oxide layer.
13. A parylene diaphragm transducer wherein the insulating layer between the conducting layers is a thin layer of parylene and the parylene layer serving as a diaphragm is relatively thicker in extent.

14. A parylene diaphragm acoustic transducer including a silicon nitride layer underlying the parylene diaphragm layer in part, the silicon nitride layer defining in cooperation with the zinc oxide layer an acoustic transducer supported from the parylene layer.

5 15. An acoustic transducer as claimed in claim 14 wherein the silicon nitride layer is patterned to form one or more trapezoid shaped cantilever type acoustic transducers underlying the parylene layer and having the zinc oxide layer extending only along an edge of the silicon nitride layer that is directly supported from the underlying silicon substrate.

10 16. A parylene diaphragm acoustic transducer as claimed in claim 14 wherein a center region of the parylene diaphragm layer is occupied by a silicon nitride layer separate from the cantilever type silicon nitride transducer layers, and further having a zinc oxide layer at least partially overlying the silicon nitride layer and separately connected to electrode lines running to separate electrode terminals from the electrode terminals connected to the edged of the cantilever type acoustic transducers.

15 17. A parylene diaphragm acoustic transducer as defined in claim 16 further including a center region of the parylene diaphragm left blank by the cantilever type silicon nitride acoustic transducers, and having thereon a layer of aluminum to emphasize the movement of the parylene diaphragm.

20 18. A parylene diaphragm acoustic transducer as claimed in claim 14 further including a silicon nitride layer underlying the parylene diaphragm and defining a single cantilever type acoustic transducer underlying a portion of the parylene diaphragm layer, and further including the region of zinc oxide extending only along an edge of the cantilever type acoustic transducer supported from the underlying silicon substrate.

19. A parylene diaphragm acoustic transducer as claimed in claim 18 wherein the silicon nitride layer is generally rectangular in shape.

20. A parylene diaphragm acoustic transducer as claimed in claim 18 wherein the silicon nitride layer is generally trapezoidal in shape.

21. A parylene diaphragm acoustic transducer as claimed in claim 19 wherein the zinc oxide region extends along an edge of the acoustic transducer supported from the silicon substrate, and wherein both the zinc oxide layer and the silicon nitride layer defining the  
5 acoustic transducer are periodically interrupted extending therethrough to the parylene diaphragm layer so that the signal energy of the acoustic transducer is focused to an electrode layer connected to the supported edge thereof.

**THIS PAGE BLANK (USPTO)**



1/10

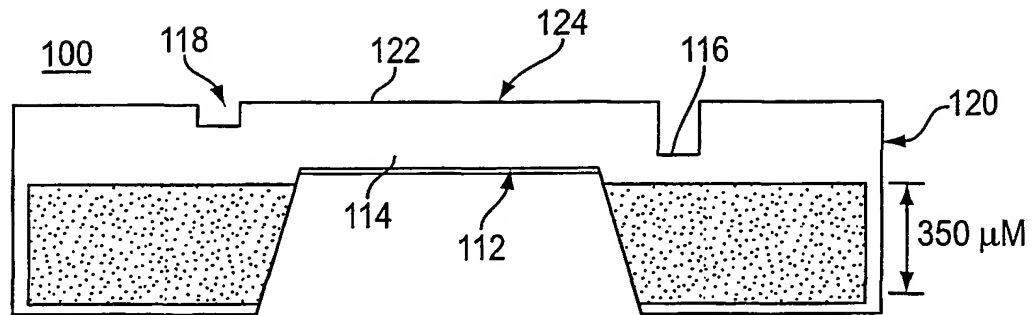


FIG. 1A

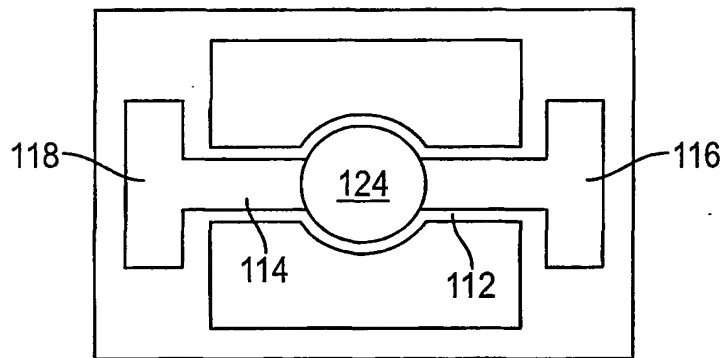


FIG. 1B

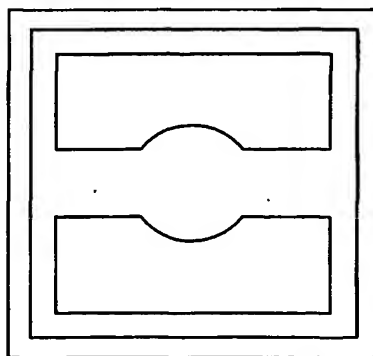


FIG. 1C

**THIS PAGE BLANK (USPTO)**

2/10

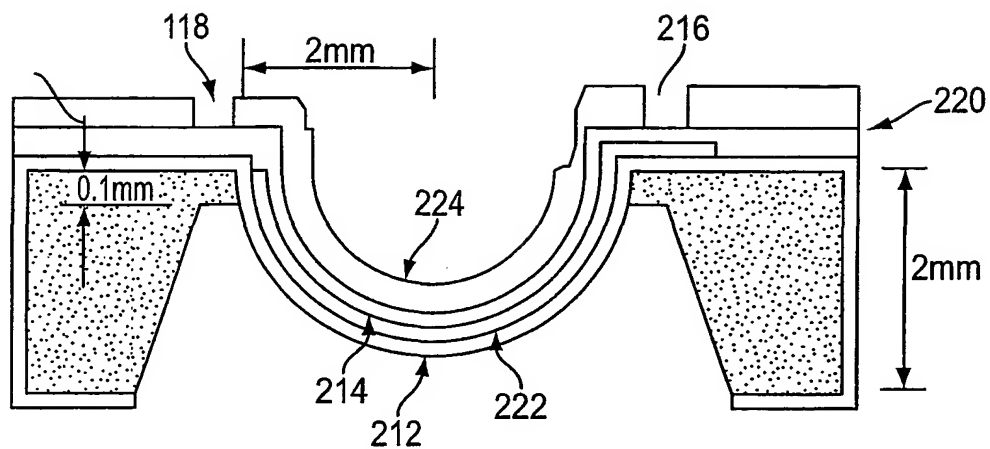


FIG. 2A

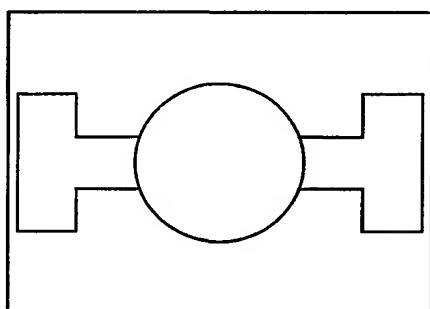


FIG. 2B

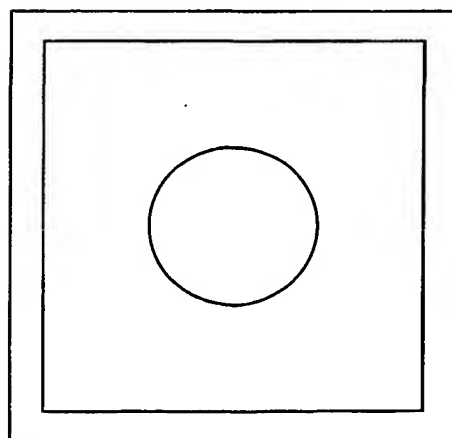


FIG. 2C

**THIS PAGE BLANK (USPTO)**

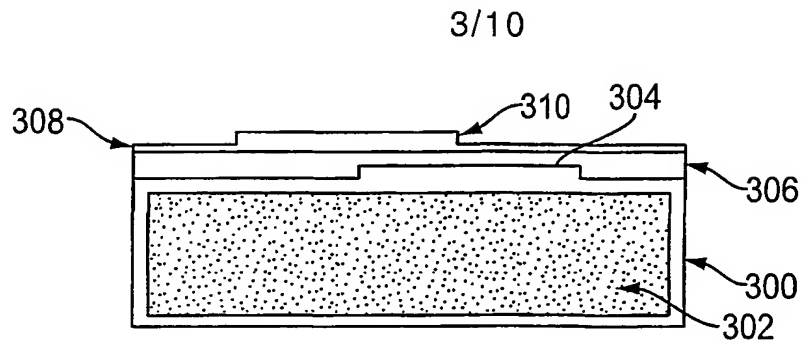


FIG. 3A

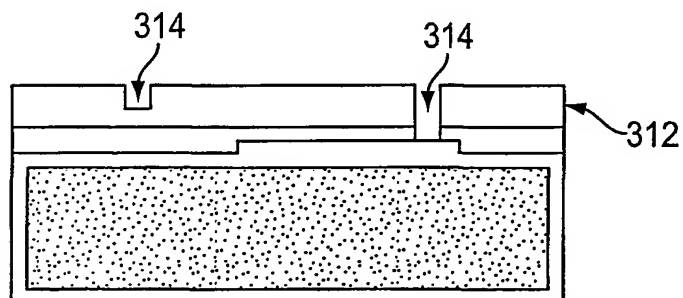


FIG. 3B

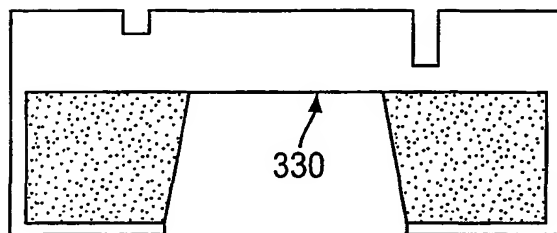


FIG. 3C

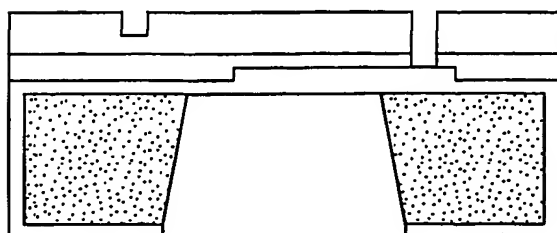


FIG. 3D

**THIS PAGE BLANK (USPTO)**

4/10

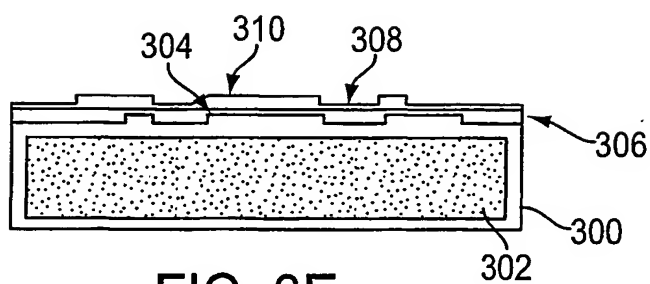


FIG. 3E

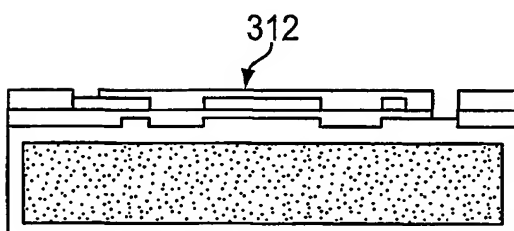


FIG. 3F

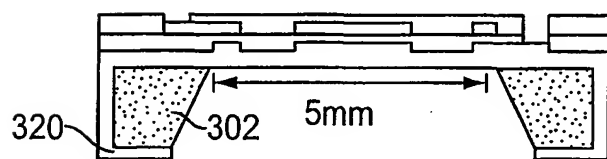


FIG. 3G

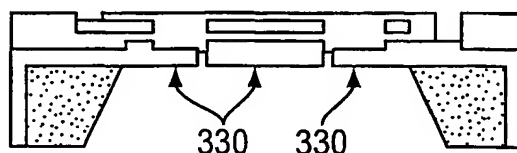


FIG. 3H

**THIS PAGE BLANK (USPTO)**



5/10

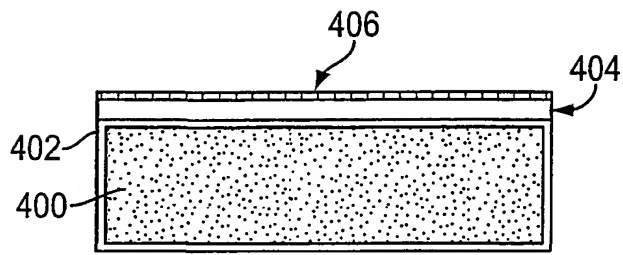


FIG. 4A

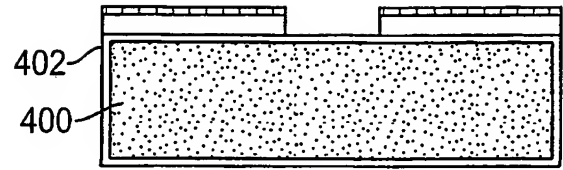


FIG. 4B

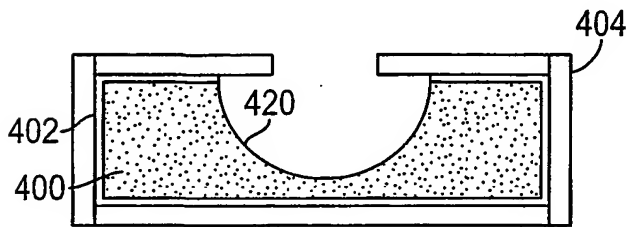


FIG. 4C

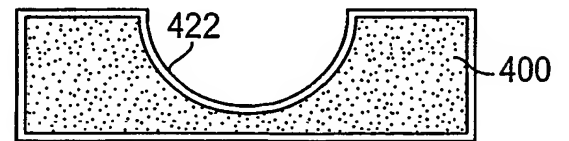


FIG. 4D

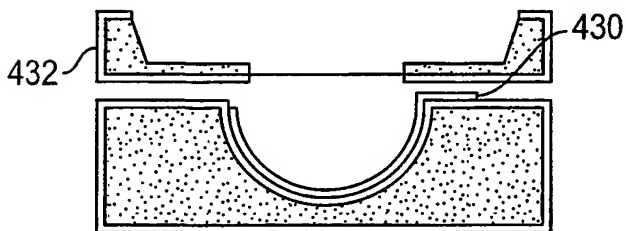


FIG. 4E

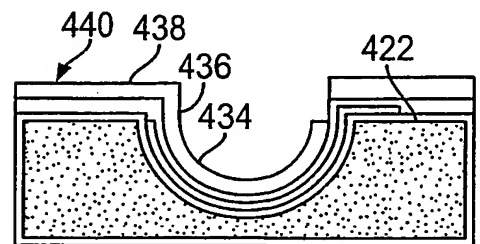


FIG. 4F

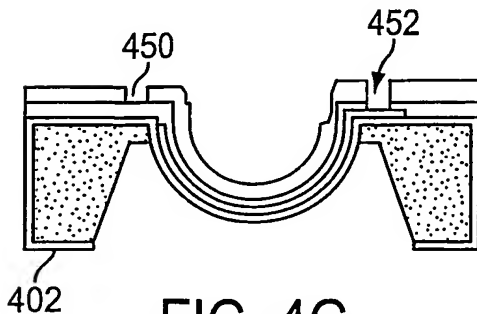


FIG. 4G

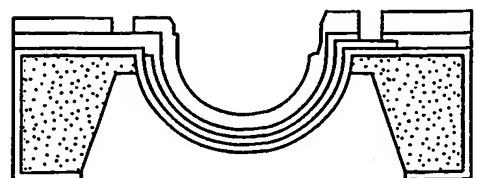


FIG. 4H

**THIS PAGE BLANK (USPTO)**

6/10

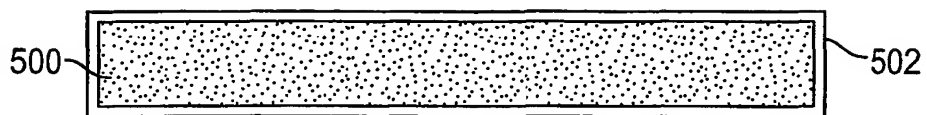


FIG. 5A

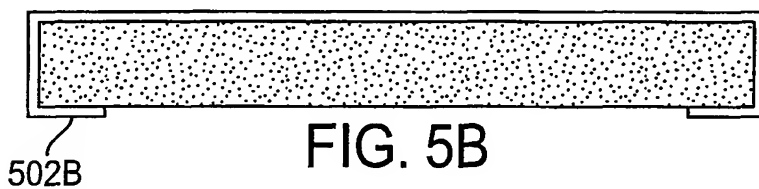


FIG. 5B

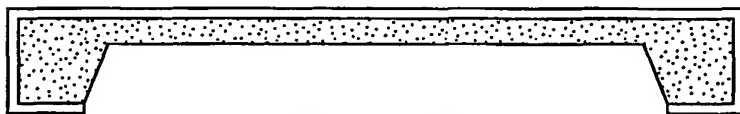


FIG. 5C

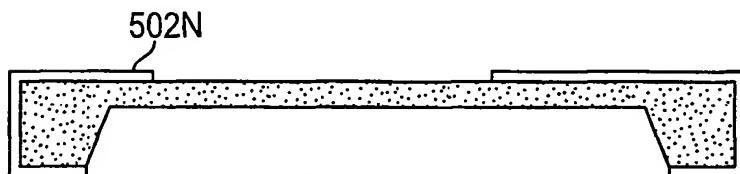


FIG. 5D



FIG. 5E



FIG. 5F

**THIS PAGE BLANK (USPTO)**

7/10

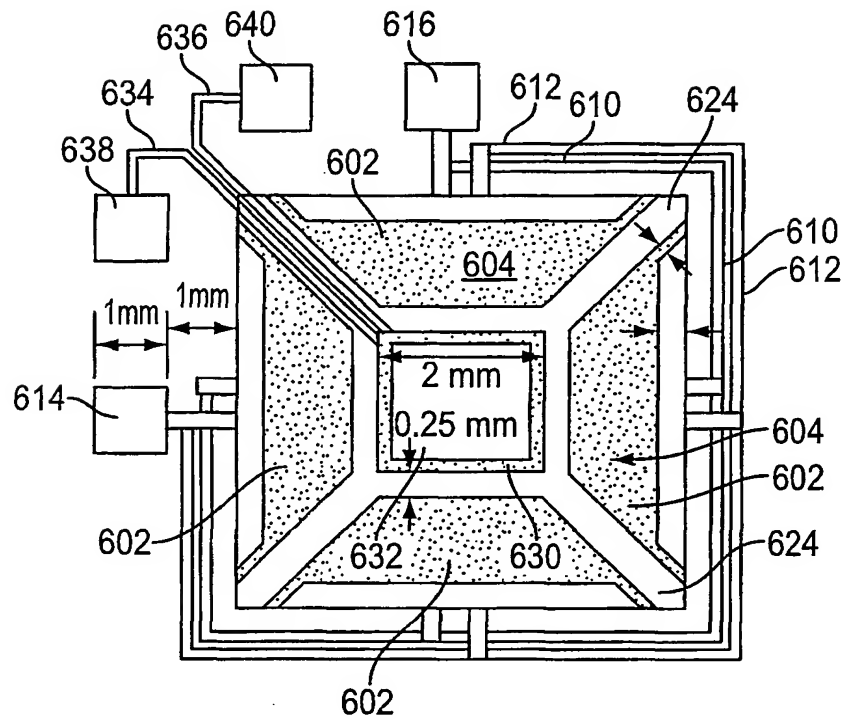


FIG. 6

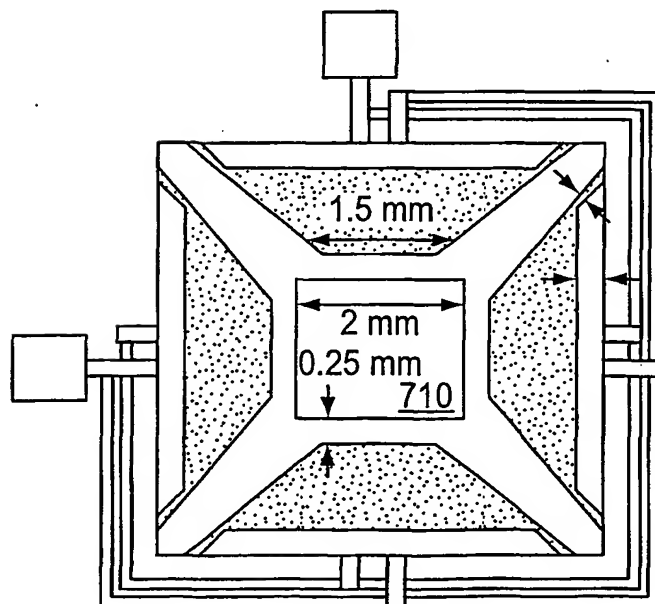


FIG. 7

**THIS PAGE BLANK (USPTO)**

8/10

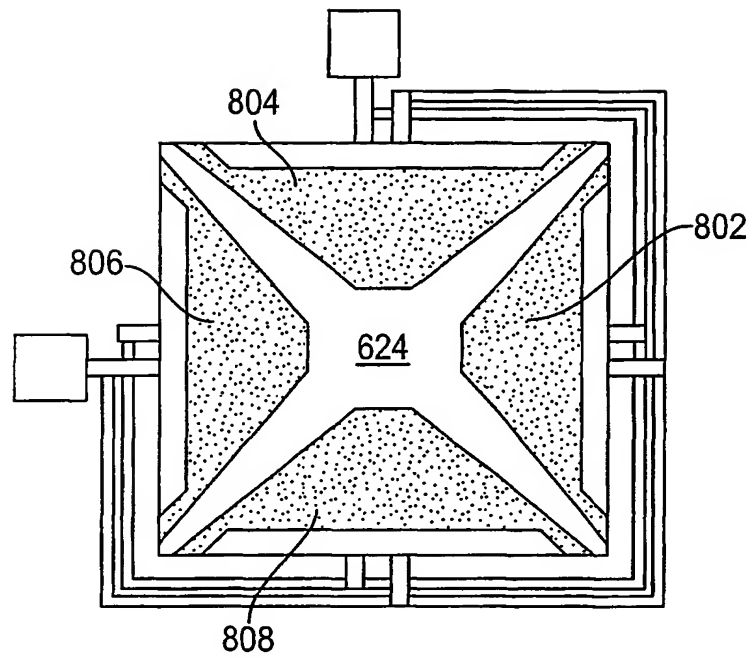


FIG. 8

**THIS PAGE BLANK (USPTO)**



9/10

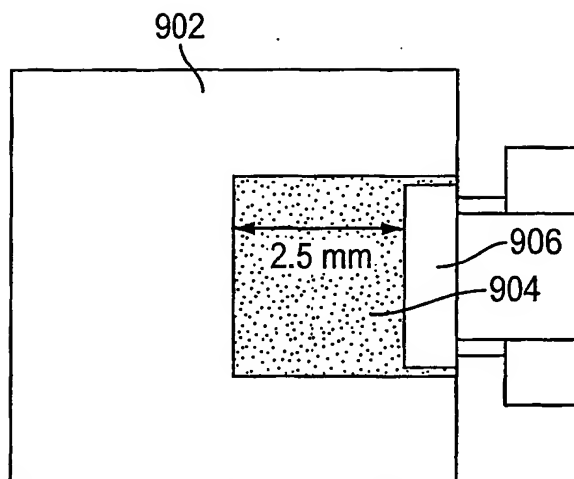


FIG. 9A

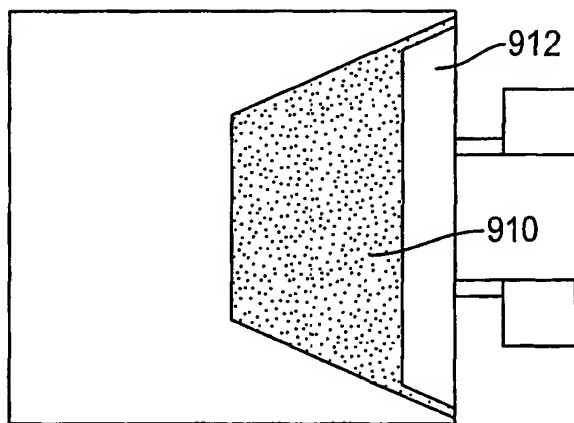


FIG. 9B

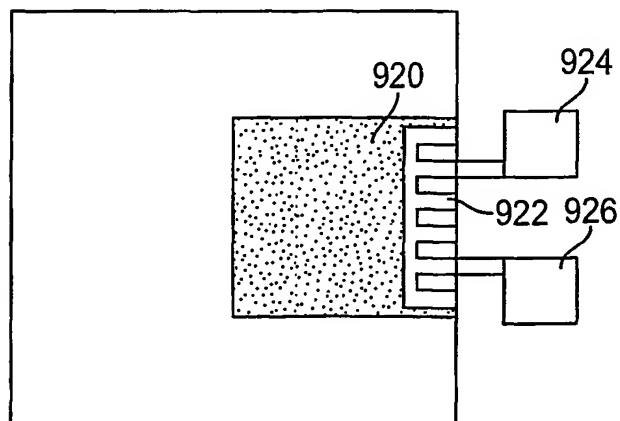


FIG. 9C

**THIS PAGE BLANK (USPTO)**

10/10

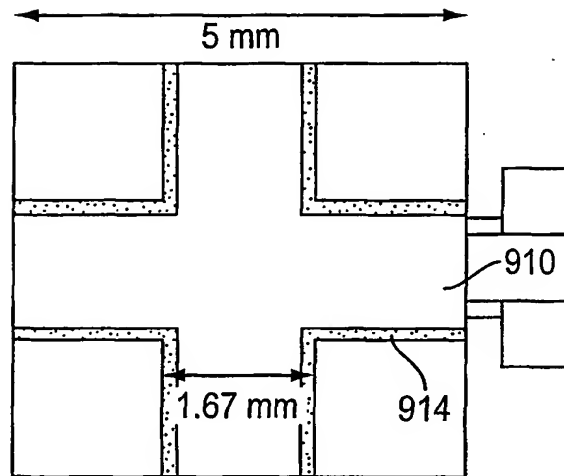


FIG. 10A

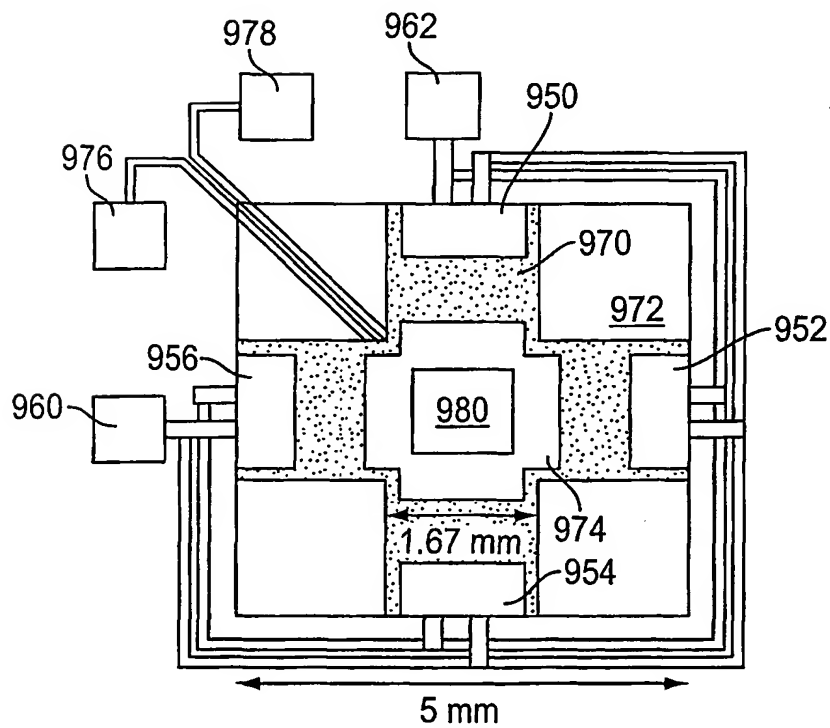


FIG. 10B

**THIS PAGE BLANK (USPTO)**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/25962

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H04R 25/00, 31/00

US CL : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 216/2, 99; 29/594; 181/158, 164, 167; 381/173, 184, 190, 191, 394, 395, 423, 426

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
WEST (USPATFULL, JPO abstracts, EPO abstracts, WPIDS, IBM TDB)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,783,821 A (MULLER et al) 08 November 1988 (08.11.1988), column 2, lines 6-34.	1-21
Y	US 5,209,118 A (JERMAN) 11 May 1993 (11.05.1993), column 6, line 65-column 7, line 8.	1-21
Y	US 5,490,220 A (LOEPPERT) 06 February 1996 (06.02.1996), column 4, lines 47-64).	6-11, 14-21
A	US 4,607,145 A (RAVINET et al) 19 August 1986 (19.08.1986), column 2, lines 50-53.	
A	US 5,870,351 A (LADABAUM et al) 09 February 1999 (09.02.1999), column 4, lines 51-59.	
A	US 5,479,061 A (BOBBIO et al) 26 December 1995 (26.12.1995).	
A	WO 99/24744 A1 (CALIFORNIA INSTITUTE OF TECHNOLOGY) 20 May 1999 (20.05.1999).	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:		"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

07 December 2000 (07.12.2000)

Date of mailing of the international search report

29 DEC 2000

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703)305-3230

Authorized officer

Anita Alanko

Telephone No. 703-308-0661

Jean Proctor *J.P.*  
Paralegal Specialist

**THIS PAGE BLANK (USPTO)**